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# RESEARCH AND DEVELOPMENT OF CONTROL ACTUATION SYSTEMS FOR AIRCRAFT

## The Evaluation of a Force Sharing and an Active-On-Line Fly-By-Wire Actuation System

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FLIGHT DYNAMICS LABORATORY
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This report describes the test evaluation of two Fly-By-Wire development demonstrators submitted to the Air Force for evaluation. The demonstrators were submitted to the Air Force under contract by Grumman Aerospace Corporation, Bethpage, New York. One demonstrator was a force sharing mechanization constructed for Grumman Aircraft by Bertea Corporation of Irvine, California. The other demonstrator was an active-on-line mechanization constructed for Grumman Aerospace Corporation by National Waterlift Corporation of Kalamazoo, Michigan.

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For the evaluation, the demonstrators were set up with specific performance characteristics which had been used for previous tests performed on other FBW mechanizations. Except where special testing was warranted to investigate potentially unique characteristics of a particular system, the same test procedures were used for both demonstration systems.

The report describes the systems evaluated, the test procedures and presents the test results obtained.

## FOREWORD

The effort described in this document was performed by Dynamic Controls, Inc., of Dayton, Ohio, under Air Force Contract F33615-77-C-3077. The contract was performed under Project Number 24030212 entitled "Flight Control Actuation Systems Development". Work under the contract was carried out in the Flight Dynamics Laboratory AFWAL/FIGL, Flight Control Division at Wright-Patterson Air Force Base utilizing United States Air Force facilities. The work was administered by Gregory J. Cecere, AFWAL/FIGL Project Engineer and Jean Barbour, Engineer in Training.

This report covers work performed between June 1977 and February 1979. The technical report was submitted by the author in August 1979.

The author wishes to express his appreciation to the Dynamic Controls, Inc. personnel Harry W. Schreadley and William G. Talley for their contributions in the areas of analysis and testing associated with the effort.

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## LIST OF ABBREVIATIONS AND SYMBOLS

| | |
|---|---|
| A | Area |
| $A_1$ | Isolation piston drive area |
| $A_2$ | Damping spool drive area |
| $D_b$ | Decibel |
| GPM | Gallons per minute |
| Hz | Hertz |
| $K_1$ | Isolation piston spring rate |
| $K_2$ | Damping spool spring rate |
| M | Mass |
| $P_r$ | Return pressure |
| $P_s$ | Supply pressure |
| $P_{si}$ | Pounds per square inch |
| q | Dynamic pressure |
| $Q_1$ | Flow generated by the isolation piston |
| $Q_2$ | Flow through washout orifice |
| $Q_3$ | Flow used by damping spool |
| $R_1$ | Rolloff orifice resistance |
| $R_2$ | Washout orifice resistance |
| $x_s$ | Surface motion |
| xip | Position of isolation piston |
| X | Horizontal ordinate value |
| $\Delta X$ | Horizontal ordinate difference |
| $X_{sp}$ | Damping spool position |
| Y | Vertical ordinate value |
| $\Delta Y$ | Horizontal ordinate difference |

## 1. INTRODUCTION

This report describes the laboratory evaluation of two Fly-By-Wire demonstrators obtained for that purpose by the Air Force from the Grumman Aerospace Corporation of Bethpage, New York. One demonstration unit was manufactured by the Bertea Corporation of Irvine, California, and the other by National Waterlift Corporation of Kalamazoo, Michigan. This report describes the testing approach, the system configurations tested and the test results for the two demonstrators.

The demonstration unit manufactured by Bertea Corporation is a force sharing configuration with the parallel operating control channels connected together at the mechanization output. All channels contributed to the mechanization force output. The demonstration unit manufactured by the National Waterlift Corporation is an active-on-line configuration with one of the parallel operating control channels generating the force output of the mechanization. The other channels generate little or no force until failure of the active channel.

Both demonstration units were supplied in two sections, consisting of the control electronics and the electro-hydraulic actuator. Both units provided for a wide variation of the mechanization parameters associated with the electronic portion of the demonstrators. The actuators of both demonstrators are designed to position the control spool of a power actuator and not as a complete Fly-By-Wire mechanization for controlling an aerodynamic surface.

The testing procedure used for evaluating the two demonstration units established the electrical parameters at specific values. The values used were selected to allow direct comparison of the performance parameters with other Fly-By-Wire configurations evaluated by Dynamic Controls, Inc. under previous contract efforts with the Air Force. Three different mechanization variations for the force sharing system were evaluated. The mechanization variations were associated with force equalization networks provided as an integral part of the demonstration unit. One configuration of the active-on-line demonstration unit was evaluated.

This evaluation testing was conducted as part of an overall evaluation of general Fly-By-Wire mechanizations for aircraft control systems. The overall evaluation is directed at providing information which will allow selecting one or more basic configurations for new aircraft incorporating Fly-By-Wire control systems. From a performance aspect, the use of Fly-By-Wire control allows much greater component commonalty for the flight control systems than the mechanical mechanizations used in the past. However, the Fly-By-Wire systems generated to date for both development and production systems have very little commonalty of approach or hardware. The continuing development of new configurations to perform the same control functions is costly in time and money. The common use of one or two basic Fly-By-Wire configurations for all new aircraft would allow improving the reliability and producibility of the basic systems, rather than expending the same resources in developing a different system for each new aircraft design.

## 2. TEST PROCEDURE

### 2.1 Introduction

The objective in testing the two actuator configurations was to establish the performance parameters and redundancy operating characteristics of the mechanization as a control element in the Fly-By-Wire control system. For this evaluation, the actuator and control console were treated as a "black box" and the output of the actuator for selected inputs (both electrical command and hydraulic power) was measured. Since the control console was not representative of flight hardware, electrical supply power input variations were not included in the evaluation. Since a redundancy mechanization is supposed to continue its control element function after selected failures, the evaluation measured the actuator performance before and after injected failures.

In general, the following evaluations were conducted:

1. Evaluation of input-output performance
2. Evaluation of transients during failure removal
3. Evaluation of failure trip sensitivity

The parameters measured for the input-output performance evaluation were:

a. Threshold - static and dynamic

b. Frequency response and distortion - small and large signal

c. Linearity and Hysteresis

d. Time response - large and small step input

These performance parameters were measured under the conditions of no failures, after selected failures, and with input deviations near the failure trip level for the particular input. The failure transient evaluation documented the actuator output change during the failure correction action due to hydraulic or electrical failures. The failure trip sensitivity testing documented the variation of electrical or hydraulic inputs which caused the actuator to indicate a failure.

In setting up the operating points for the two demonstration units, the nominal frequency response and failure detection levels were adjusted to either approach or meet the general values used for testing FBW mechanizations evaluated previously. The operating points were established by changing the gain parameters of the mechanization within the electronic components contained in the control consoles. The nominal frequency response (the point at which the phase lag equals $-90^{\circ}$ or the amplitude response is -3 Db) was set at 20 Hz. This is consistent with the response requirements for the stability augmentation function of a high performance flight control system. The detection levels for the failure detection were established at 50% of the input level which causes saturation of the servovalve output. The input levels assigned for full stroke command were set at a level that allowed at least a 4% input level command to be applied to the mechanization at any frequency without incurring saturation distortion.

In presenting the test results, the measured performance parameters are given in terms of % of the input level for full output stroke wherever applicable. This normalizes the data presentation for comparison with the performance of other mechanizations.

## 2.2 General Test Procedure

The following is the general test procedure used for evaluating the demonstration systems. This procedure defines the measured parameter and states the general method used in making the measurement. The procedure is divided into the following sections:

1. Performance Measurements
2. Failure Effect On Performance
3. Input Deviations Effect
4. Failure Removal Transients

### 2.2.1 Performance Measurements

#### 2.2.1.1 Threshold

| | |
|---|---|
| Static Threshold | "The minimum input change from zero level which causes a measurable output change." |
| Procedure | Apply a slowly increasing + input until a measurable output change occurs. Repeat for - input. Threshold is indicated by the minimum input change for a measurable output change. |
| Dynamic Threshold | "The input level (at a particular frequency) required to cause a measurable output level." |
| Procedure | A sinusoidal input at a selected frequency of 50% of the bandpass of the actuator is applied to the actuator. The amplitude of input to create a measurable output indicates the dynamic threshold. The bandpass of the actuator is defined as the frequency at which -3db amplitude or $90^{\circ}$ phase shift occurs (whichever is lower in frequency). |

2.2.1.2 Frequency Response

"With a sinusoidal actuator input, the frequency response of the actuator is the output of the amplitude ratio and phase shift as a function of frequency."

Procedure

A sinusoidal input of an amplitude which is:

a. large enough to minimize the nonlinearity distortions of threshold and hysteresis

b. small enough to avoid velocity saturation in the frequency range of interest is applied to the actuator input. The ratio of output amplitude to input amplitude and output phase relative to input is recorded.

   The curves of the amplitude ratio and phase indicate the frequency response.

2.2.1.3 Distortion

"The amount of deviation of the actuator output from the input waveform."

Procedure

The harmonic distortion, at the input level used to measure the frequency response, is recorded at sinusoidal input frequencies of 10%, 50% and 100% of the bandwidth.

2.2.1.4 Linearity

"The deviation of output vs. input from a straight line relationship."

Procedure

Apply an input from - max. to + max. input while recording the corresponding output position. Linearity is indicated by max. deviation of the plotted output vs. input from a straight line drawn between zero and a point which minimizes the maximum deviation of the plotted curve from the straight line. Repeat for + input to - input.

2.2.1.5 Hysteresis

"The non-coincidency of loading and unloading curves."

Procedure

Apply a slowly varying input to the actuator at 10% and 1% of max. input in the following sequence while recording the actuator output position:

0 to + direction input

+ input to - direction input

- input to + input

From the plot of output vs. input, the hysteresis is indicated by the difference between + direction actuator output position and - direction output position for the same input level.

2.2.1.6 Time Response

Saturation Velocity

"The maximum velocity at which the actuator is capable of moving in each direction."

Procedure

With the actuator at zero position, a maximum amplitude input is applied to the actuator while the actuator motion vs. time is recorded. The test is conducted for both directions of actuator motion. The slope of the position vs. time record indicates the saturation velocity.

Transient Response

"The time response of the actuator output to an applied step input."

Procedure

Apply a step input to the actuator and record the corresponding actuator motion. The amplitude of the step should be:

a. large enough to minimize the nonlinearity distortion of threshold and hysteresis

b. small enough to avoid velocity saturation.

The plot of actuator output motion vs. time indicates the transient response.

2.2.2 Failure Effect on Performance

2.2.2.1 Failure Effect

"The change on the performance of a redundant actuator due to input failures or internal failures of actuator components."

Procedure

Inject hydraulic or electrical input failures into the actuator under test to cause it to operate in its "failure operational" modes. For each mode, measure the performance by repeating the Performance Measurement Tests. The input levels should be maintained at those used for the "no failure" performance tests, unless the performance changes dictate different levels in order to obtain reasonable test data.

2.2.3 Input Deviations Effect

2.2.3.1 Electrical Deviations

"The change of electronic inputs, both power and control, with respect to the normal values and/or each other."

| | |
|---|---|
| Procedure | Adjust the electrical inputs one at a time until either the maximum expected deviation of the input is reached or the failure trip level is reached. Section 2.1 will be measured with each electrical input deviation adjusted one at a time to the maximum deviation expected or a value of 90% of that which will cause a failure trip. |

2.2.3.2 Hydraulic Deviations

"The change of hydraulic pressure inputs with respect to the normal values."

| | |
|---|---|
| Procedure | Adjust the hydraulic inputs one at a time until the maximum expected deviation or a failure trip level is reached. The performance parameters of Section 2.1 will be measured with each hydraulic input adjusted one at a time to the maximum deviation expected or a deviation value of 90% of that which will cause a failure trip. |

2.2.4 Failure Removal Transients

2.2.4.1 Electrical Failure Transients

"The change in actuator output during failure corrective action due to electronic input failures causing transfer from one operational mode to another."

| | |
|---|---|
| Procedure | Apply a slowly changing input to one control channel of the actuator. Record the actuator output change during the corrective action of actuator. Repeat the test for each control channel input and failure mode condition. Repeat for a hardover step input.<br><br>Apply a sinusoidal input to all channels. Open each input while recording actuator output. |

2.2.4.2 Hydraulic Failure Transients

"The change in actuator output during failure removal corrective action due to hydraulic input failures causing transfer from one operational mode to another."

| | |
|---|---|
| Procedure | Apply a slowly decreasing hydraulic input to one control channel of the actuator. Record the output change during the corrective action of the actuator. Repeat the test for all hydraulic inputs. |
| | Repeat the preceding test with a rapid decrease of hydraulic input pressure. |

2.3 Test Configuration

Figure 1 is a block diagram schematic of the instrumentation, command and power connections used during the laboratory evaluation of the two demonstration systems. As shown on Figure 1, a Bafco Servo Analyzer was used with an Esterline Angus XYY' plotter for making the frequency response measurements. The Hewlett Packard Model 333A distortion analyzer was used for the input and output signal distortion measurements. The Wavetec Model 144 sweep generator and the XYY' plotter were used for making the hysteresis and linearity measurements. Failure removal transients were recorded on the Brush 200 recorder. The power required for operating the control consoles of each demonstrator was connected to the laboratory 60 Hz 110 volt power. As shown on Figure 1, the input commands were run from a general purpose switch and potentiometer panel. This panel allowed individual variation of the 4 inputs for the control channels of the demonstration systems and the injection of hardover input commands. Hydraulic power for the evaluation was obtained from the 30 GPM, 3000 psi laboratory pumping system. Supply pressure for the demonstration systems was connected through two pressure reducing valves to allow evaluating the effect of hydraulic pressure degradation on the performance of the demonstration system.

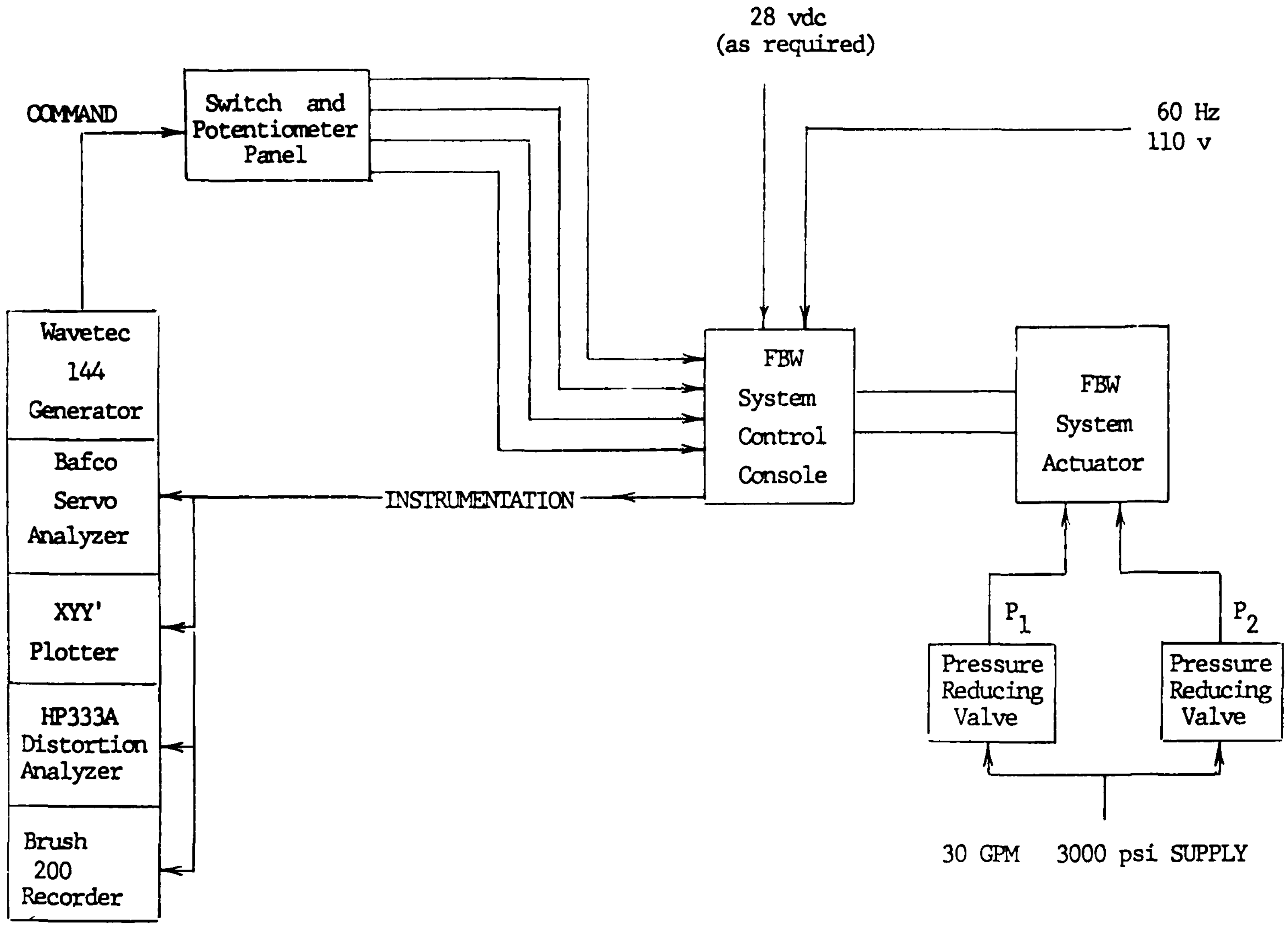



FIGURE 1 Schematic of the Instrumentation, Command and Power Connections During Evaluation

# 3. FORCE SHARING FBW SYSTEM EVALUATION

## 3.1 Introduction

The Bertea FBW Demonstrator was evaluated in three separate configurations. These configurations were the following:

1. Configuration A - Force summed with no equalization or integration
2. Configuration B - Force summed with equalization and no integration
3. Configuration C - Force summed with equalization and integration

The general characteristic of a force summed system is that offset or null shifts in individual control channels due to normal variations of the components of the channels cause force summing fights. The force fights lead to threshold levels greater than that of a single channel. The testing of Configuration A evaluated the force summed configuration as a basic configuration. Configuration B and C are configurations which include feedback techniques intended to reduce the force fight between control channels and eliminate the threshold problems associated with those force fights. Therefore, the purpose of the evaluation of Configurations B and C was to establish the characteristics of operating the basic force summed system with the equalization and integration loops incorporated into the mechanization.

In evaluating the mechanization for specific failures, no attempt was made to create internal failures in either the console electronics or the actuator. The failures simulated were created by failing the inputs to the demonstrator (electrical command and hydraulic power). These failures did not address directly internal failure modes possible within the particular mechanization. It is assumed that common mode failures are not part of the mechanization design and that the effect of internal failures of a control channel fall within the extremes of the hardover and slowover input failures used for the evaluation testing.

The Bertea FBW demonstrator was designed to represent the secondary actuator approach to a FBW mechanization. The output of the demonstrator would normally be connected as an input to the power actuator driving a control surface. The test results are of a secondary actuator and not the power actuator of a FBW system.

### 3.2 Hardware Description

The actuator package for the force-summed configuration is an electrohydraulic four channel configuration. Three of the channels function in a normal force vote and the fourth channel operates at a 50% force limit in a standby mode. Upon a failure of one of the three other channels, the force output limit on the standby channel is removed. The actuator package as tested weighed approximately 30 lbs and measured 13 X 8 X 8 inches. As shown in Figure 2, the four separate actuator modules are mounted on a common base. The output of each actuator is attached to a force summing bar which is hinged and incorporates an output clevis. Each actuator is controlled by a single stage jet pipe servovalve having a flow capability of .174 GPM at maximum input current and 3000 psi supply pressure. The actuator also incorporates differential pressure equalizers to provide load equalizing feedback when the differential pressure across an actuator drive area exceeds a specific design level. A solenoid valve is incorporated into each actuator to allow disconnecting hydraulic pressure to the jet pipe servovalve when a channel failure is detected. The characteristic of a jet pipe servovalve when depressurized is to act as a bypass path across the actuator drive area. Channel 4 uses an additional solenoid which, when energized, provides that channel with a 100% force capability.

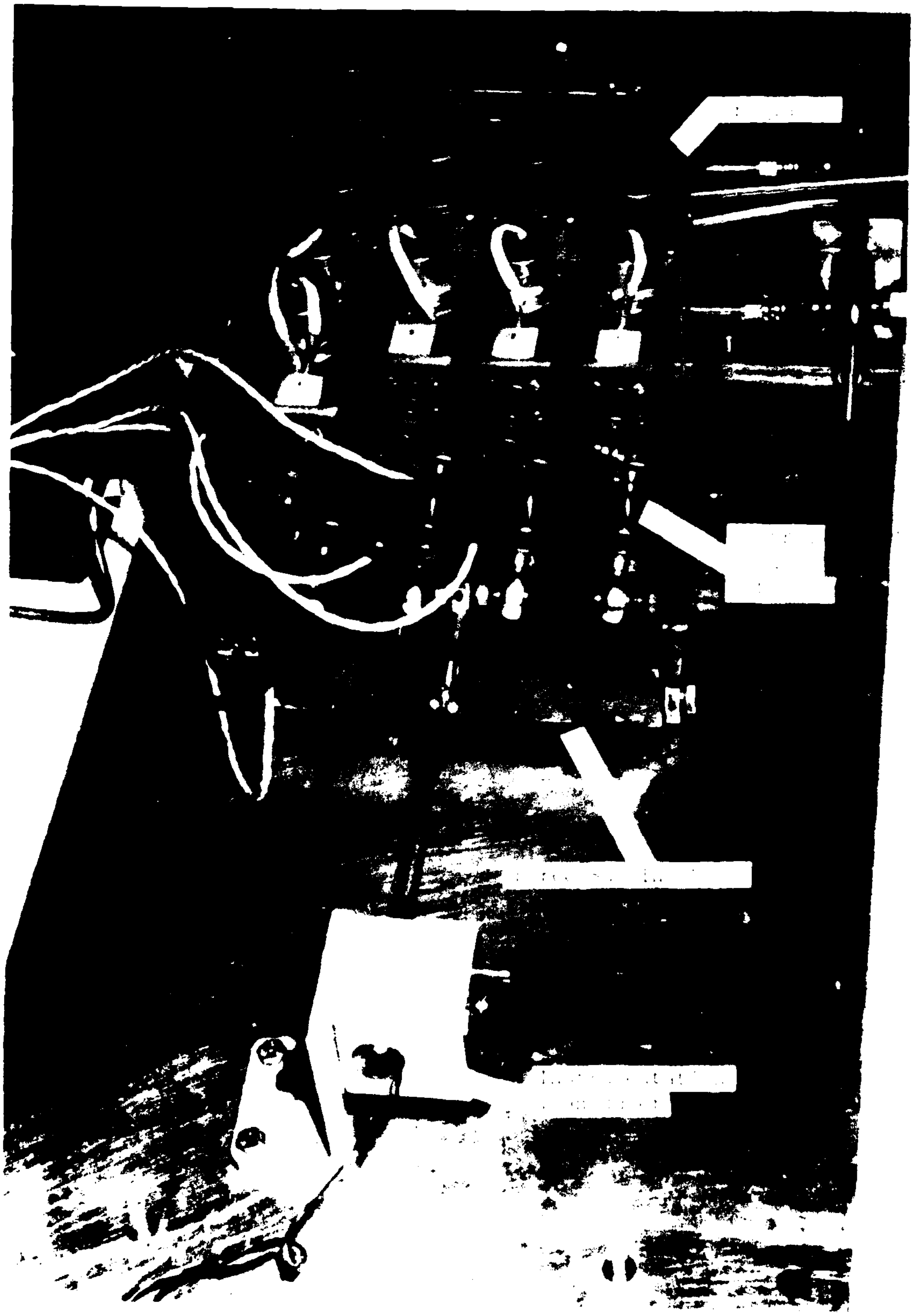


FIGURE 2 Force Sharing Demonstration System Actuator

The spool of the equalizer is designed to bypass the actuator drive area when the differential pressure exceeds 1200 psi. The equalizer of the standby actuator incorporates a detent piston on each end. The detent pistons are connected to a solenoid valve. Pressurization of the detent piston by the solenoid valve changes the force limit from 50% to 100% (the 1200 psi limit). Each actuator incorporates a linear variable-differential transformer mounted inside the actuator piston rod. This transducer is used to provide position feedback for the channel's actuator position.

The electronic controller supplied with the actuator provides failure detection, voting and servo loop control of the demonstration actuator. Figure 3 shows the control console used with the demonstration system. The control console electronics include four servo channels. Each servo channel incorporates two servoamplifiers (a model and an active amplifier), a demodulator, crossover network, threshold and failure logic circuits and a solenoid driver. The active servoamplifier of each channel is connected to the servovalve. The model servoamplifier is connected to a dummy load. A comparison of the model and active servo output currents is used to detect servoamplifier failures of each channel. The demodulator of each channel is used to convert the feedback transducer output signal to a DC control voltage for closing the control loop of the actuator. The crossover network is used to convert the output of the variable reluctance transducer (used with the force equalizer) to a DC voltage. The threshold circuits are used with the failure logic and receive signals from the servoamplifier outputs and the equalizer transducers.

The failure logic processes the outputs of the threshold circuits and includes a time-delay circuit for declaring a failed channel. Figure 3 shows several electronic modules positioned between the control console and the demonstration actuator. These modules are the electronics used with the integration and equalization feedback

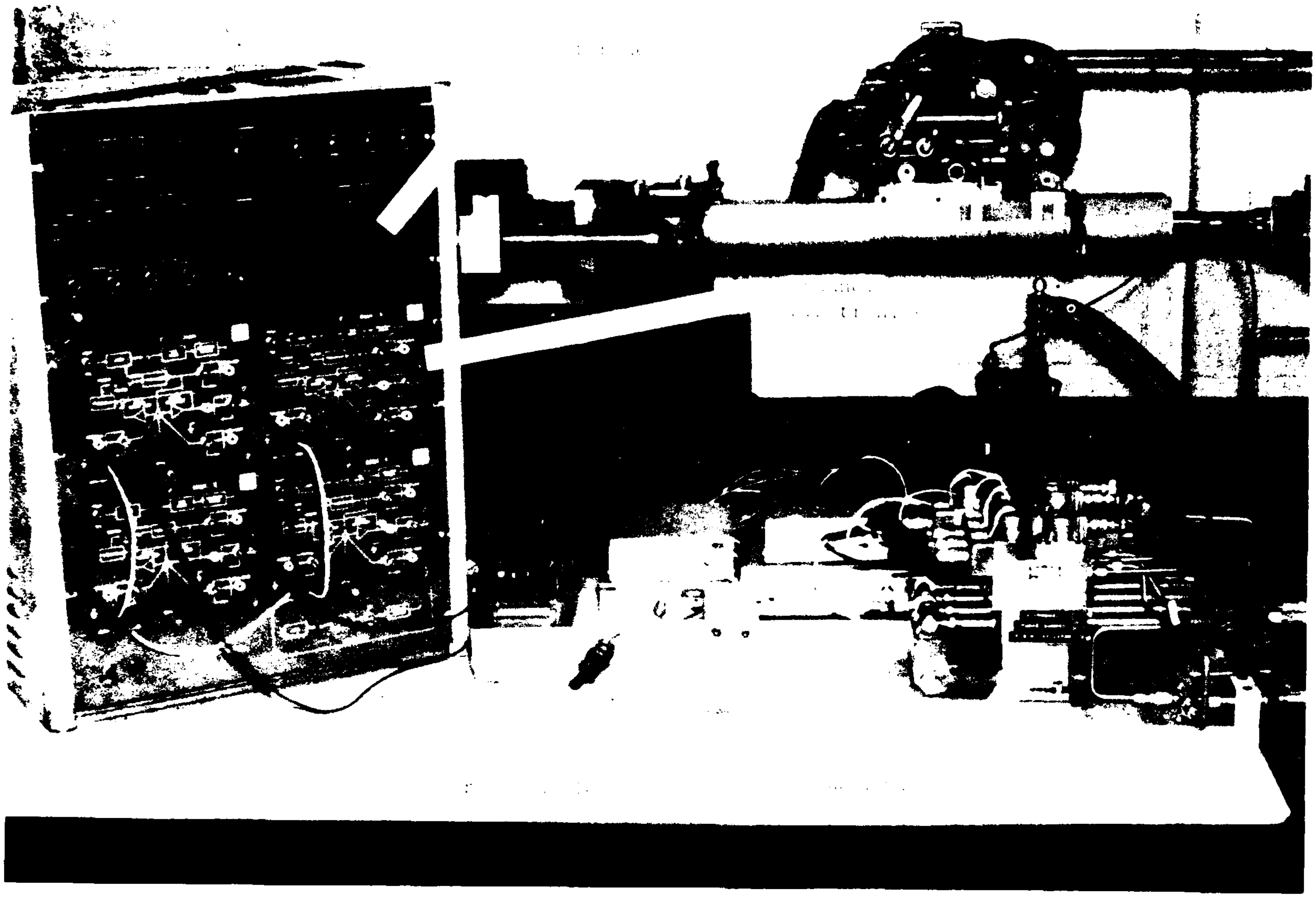


FIGURE 3  Force Sharing Demonstration System

techniques for Configurations B and C. The control console incorporates a test panel for failure simulation purposes.

### 3.3 Operational Description

Four channels are used with the force summing mechanization, with the fourth channel being required to meet the dual fail operate requirement. The fourth channel is kept in a low force capability or "standby" operating condition until a normal channel fails. This is done to eliminate the possibility of an even channel force fight occuring with all four channels operating together (with three channels force summed, one channel is "controlling" and the other two "cancelling" in a force fight situation). The use of the equalizer in each channel actuator acts both as a feedback device to reduce the force gain of the channels and an automatic bypass for a channel if it disagrees greatly from the other two. Note that the mechanization as designed is constrained to limited loading on the output link since the equalizers bypass the actuators at a 1200 psi load pressure across each channel actuator.

In the event of a failure causing an actuator to disagree with the other two actuators, the equalizer spool moves in response to the differential pressure across the actuator drive area (created as the actuator tries to move to a new position against the force output of the other two channels). When the equalizer output signal reaches a predetermined level, the logic trips causing the channel to be declared failed and depressurized.

Besides the equalizer output failure detection circuitry, failure detection circuitry for passive servoamplifier failures is incorporated into the mechanization. Servoamplifier failures which would not create a differential pressure across the equalizer spool are detected by comparing the channel's servoamplifier output with the model servoamplifier used in each channel. For failures detected by this circuitry, no corrective action is taken although the failure is indicated by a warning light.

Figure 4 is taken from a schematic (provided by Grumman) of one actuator channel as used in the demonstrator. Specific system parameters used for the evaluation testing of the demonstrator were the following:

| | |
|---|---|
| Operating Pressure | 3000 PSI |
| Maximum Actuator Stroke | $\pm$ .190 inches |
| Nominal Position Loop Gain | 125 Radians/sec. |
| Failure Detection Level | 50% (4 Ma) of saturation valve current |
| Maximum Input Control Voltage | $\pm$ 10 volts |

The values used for the actuator stroke and loop gain were changed from the original configuration of the demonstrator in order to increase the input level causing rate saturation of the actuator at high frequencies. As originally received, input levels greater than 1% of the input level for maximum actuator position caused saturation distortion of the output at high frequencies. The nominal loop gain as received was also greater than 314 radians/sec. The 1% input level for rate saturation is lower than that typical of a general FBW system and the 50 Hz response (corresponding to the loop gain of 314 radians/sec) greater than that required for a high performance FBW system. In order to increase the % input level causing rate saturation, the system position loop gain was decreased to the 125 radians/sec and the stroke for maximum position of the actuator was decreased below the mechanical limits of the actuator. This allowed an input level of 4% of the maximum command input without rate saturation of the actuators. These changes were made with the understanding and approval of the Grumman personnel providing the demonstrator for evaluation.

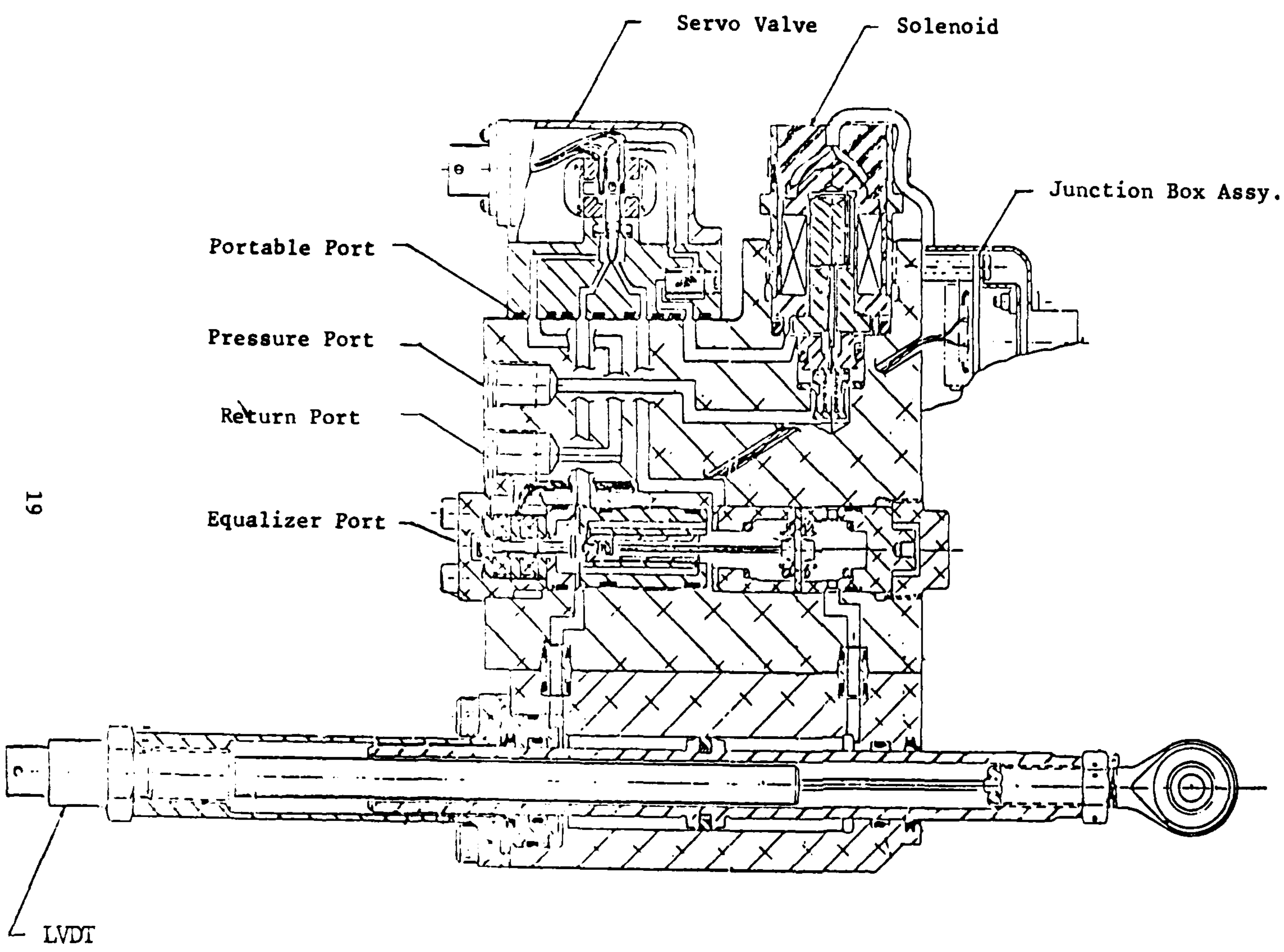



FIGURE 4 Four Channel Force Summed Actuator Schematic

Figure 5 is a schematic of one control channel of the mechanization with the gain values used for the evaluation testing. The values for the feedback paths of the position and equalization loops reflect the modifications made to establish the nominal loop gains for the position loop and the detection levels for the pressure equalization loops.

3.4 Specific Test Procedure - Configuration A

Table 1 lists the 27 test conditions and the values used for evaluating Configuration A of the force sharing demonstration unit. Test conditions 1 through 11 are the various operational modes of the system. For each of these operational modes, the performance measurements described in Section 2.2.1 were used to document the performance characteristics. The other test conditions correspond to the "Failure Effect on Performance" measurements described in Section 2.2.2 and the "Input Deviations Effect" measurements described in Section 2.2.3.

Test conditions 12 through 27 correspond to "Failure Removal Transients" measurements described in Section 2.2.4. The test conditions 12 through 27 state both the initial conditions and the test used for creating the transient condition.

3.5 Test Results

3.5.1 General

In order to reduce the volume of test data presented in this section, the majority of the performance measurement data has been reduced to tabulated form. Since time response characteristics are not well defined by listing just one or two characteristic parameters, the step response measurements and the failure transient measurements

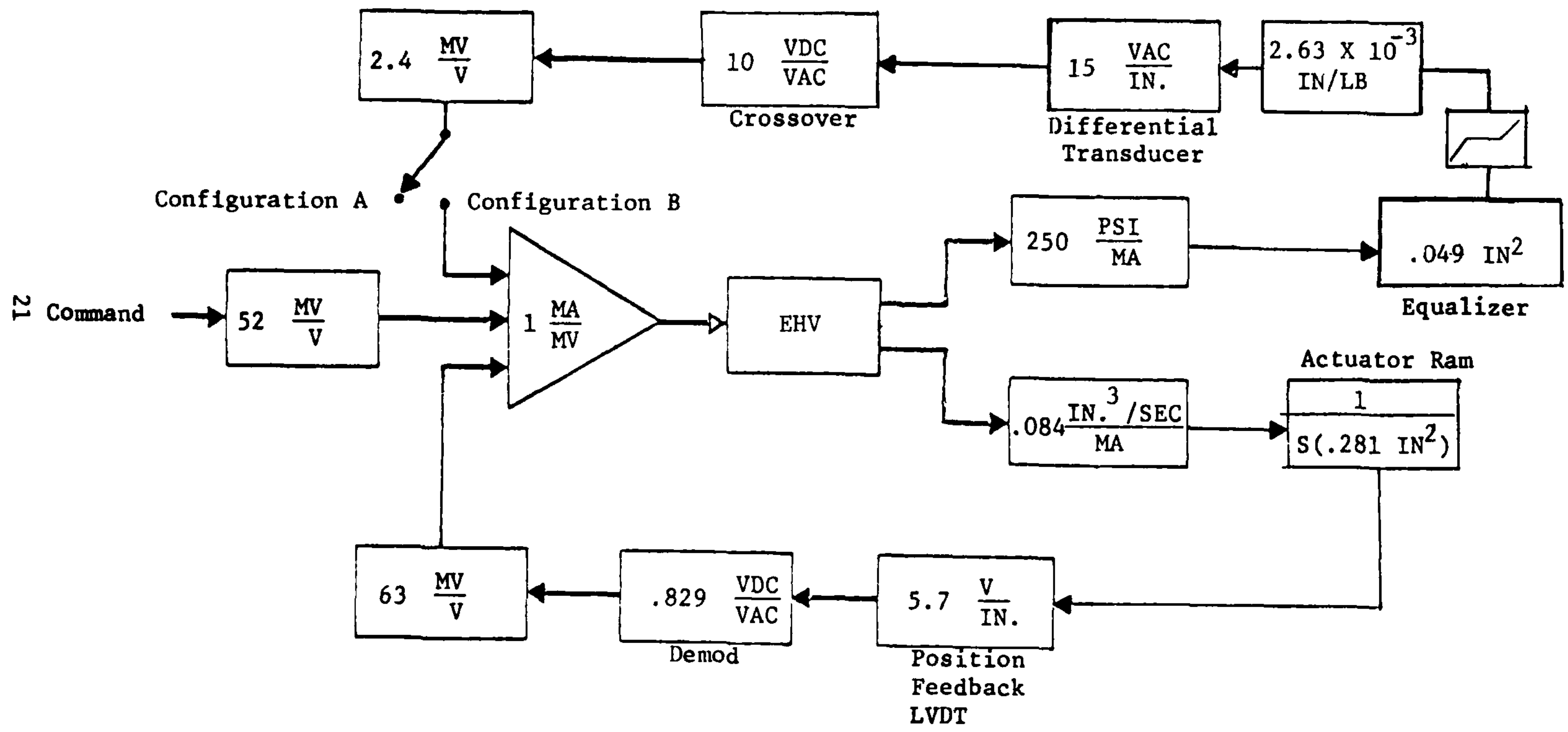



FIGURE 5 Control Circuit Schematic - Force Sharing Demonstrator

TABLE 1

TEST CONDITIONS

Grumman - Bertea Unit - Configuration A

| Test Condition | Test Condition Description |
|---|---|
| 1 | Baseline - all channels nulled, pressurized (3000 psi) and operating correctly. |
| 2 | One channel (1) electrical failure. |
| 3 | Two channels (1 & 2) electrical failure. |
| 4 | One channel (1) hydraulic failure. |
| 5 | Two channels (1 & 2) hydraulic failure. |
| 6 | One channel (1) with negative input offset (biased to 90% of trip level). |
| 7 | One channel (1) with positive input offset biased to 90% of trip level). |
| 8 | Two channels (1 & 2) with negative input offsets (both channels biased negatively to 90% trip level). |
| 9 | Two channels (1 & 2) with opposing input offsets (channel 1 biased positively and channel 2 biased negatively to 90% trip level). |
| 10 | One channel (1) with hydraulic pressure reduced to 2000 psi. |
| 11 | Two channels (1 & 2) with hydraulic pressure reduced to 2000 psi. |
| | FAILURE TRANSIENTS |
| 12 | Ground inputs to channels 1, 2 & 3 sequentially with system at 50% extend. |
| 13 | Ground inputs to channels 1, 2 & 3 sequentially with system at 50% retract. |

TABLE 1

TEST CONDITIONS (cont'd)

| Test Condition | Test Condition Description |
|---|---|
| 14 | Ground inputs to channels 1, 2 & 3 sequentially with the system operating at ½ the bandpass frequency (10 Hz) with the maximum unsaturated input. |
| 15 | Ground the inputs to channels 1 & 2 simultaneously with the system operating at ½ the bandpass frequency (10 Hz) with the maximum unsaturated input amplitude. |
| 16 | Positive hardover (+10V) sequentially applied to channels 1, 2 & 3 with the system at null. |
| 17 | Negative hardover (-10V) sequentially applied to channels 1, 2 & 3 with the system at null. |
| 18 | Positive hardover (+10V) sequentially applied to channels 1, 2 & 3 with the system biased to 50% extend. |
| 19 | Negative hardover (-10V) sequentially applied to channels 1, 2 & 3 with the system biased to 50% extend. |
| 20 | Positive hardover (+10V) sequentially applied to channels 1, 2 & 3 with system biased to 50% retract. |
| 21 | Negative hardover (-10V) sequentially applied to channels 1, 2 & 3 with system biased to 50% retract. |
| 22 | Positive hardover (+10V) sequentially applied to channels 1, 2 & 3 with system operating at ½ the bandpass frequency (10 Hz) with the maximum unsaturated input amplitude. |
| 23 | Negative hardover (-10V) sequentially applied to channels 1, 2 & 3 with system operating at ½ the bandpass frequency (10 Hz) with the maximum unsaturated input amplitude. |

TABLE 1

TEST CONDITIONS (cont'd)

| Test Condition | Test Condition Description |
| --- | --- |
| 24 | Positive hardover (+10V) simultaneously to channels 1 & 2 with the system at null. |
| 25 | Positive hardover (+10V) simultaneously to channels 1 & 2 with the system operating at ½ the bandpass frequency (10 Hz) with the maximum unsaturated input amplitude. |
| 26 | Apply a ramp of zero to 1 volt at 0.4 volts/sec (±1.0V at 0.1 Hz) to channels 1, 2 & 3 sequentially with system at null. |
| 27 | Apply a ramp of 0 to 1 volt at 0.4 volts/sec (±1.0V at 0.1 Hz) sequentially to channels 1, 2 & 3 with system operating at ½ the bandpass frequency (10 Hz) with the maximum unsaturated input amplitude. |

are presented graphically as recorded. The following results are presented in tabulated form for Conditions 1 through 11:

1. Static Threshold
2. Dynamic Threshold
3. Frequency Response
4. Distortion
5. Hysteresis
6. Saturation Velocity

For these test results reduced to table form, a sample of the data is included with the table. In addition to the tabulated performance characteristics listed above, linearity and extend and retract step responses for Conditions 1 through 11 are presented in graphical form.

In presenting the measurements of threshold and hysteresis, the results are given both in percent of the input for full actuator stroke and the input for full servovalve output flow. In terms of the percent of full actuator stroke input, the percentage value for a given amount of hysteresis reduces as the maximum stroke of the actuator increases. Presenting the percentage hysteresis in terms of the input for the maximum control valve flow describes the threshold and hysteresis characteristics in terms which allow comparing different control valve driving mechanizations independent of the actuator stroke sizing.

The test results are presented in this section in the following order:

1. Performance measurements for Conditions 1 through 11
2. Failure transients for Conditions 1 through 11
3. Failure logic detection characteristics.

3.5.2 Performance Measurements

3.5.2.1 Static Threshold

Figure 6 shows the data recorded in establishing the static threshold for Condition 1. Note that the .1 Hz ramp input is slowly increasing with increasing time. The threshold value is determined by the first input amplitude where the actuator output starts to respond to the control input. Note that the high frequency noise content of the output signal is not due to the characteristics of the position LVDT and demodulator used in the control console. The noise content is primarily made up of background noise picked up by the instrumentation lines to the recorder and is the result of the low output levels measured during the particular test. The edge of the noise shows the actuator responding to the .1 Hz input ramp. Table 2 shows the static threshold values measured for test Conditions 1 through 11.

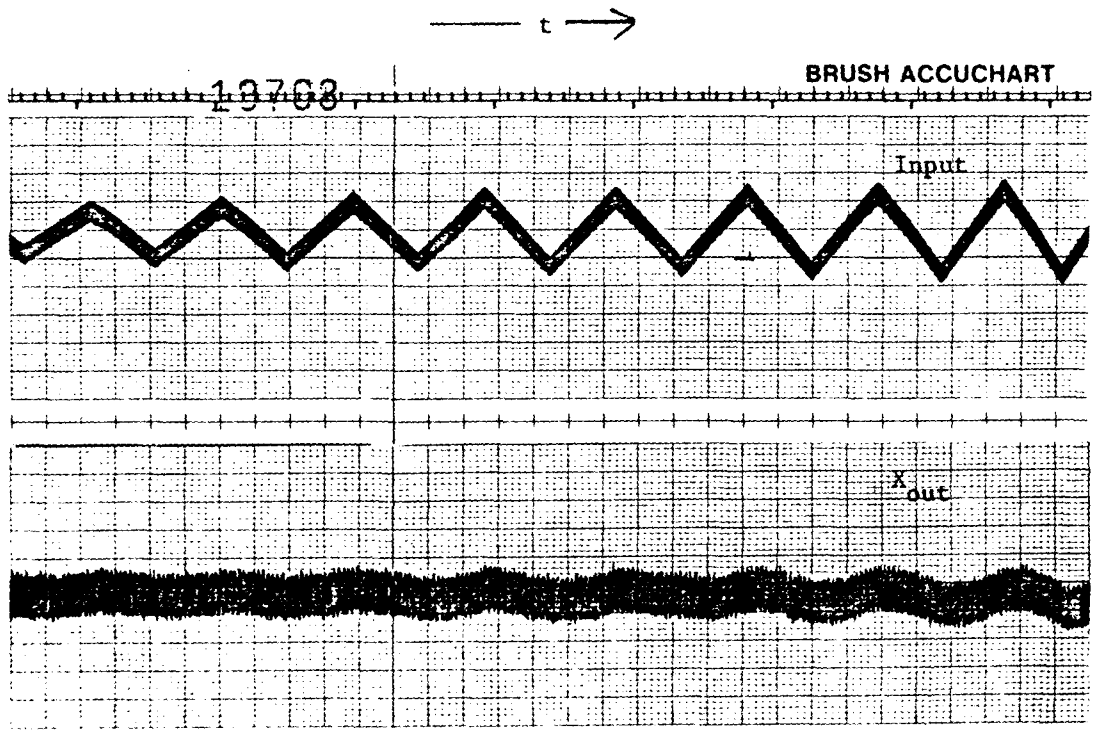
Note that the threshold in terms of the maximum input to the servovalve (% of $E_v$ Max) is above 10% for all test conditions. The threshold increases with both channel offsets and with loss of control channels. This threshold value is considerably greater than that exhibited by an electrohydraulic servovalve. Typical electrohydraulic servovalves exhibit thresholds of less than .5% of the maximum rate current (equivalent to the percent rating in terms of the maximum input voltage $E_v$). The greater threshold is the result of the low pressure gain values and force fight between channels that is inherent with the mechanization. The force sharing mechanization threshold does not compare favorably with the conventional servovalve threshold performance. Note also that the threshold in terms of the actuator stroke is less than .2%, a figure which depends on the particular stroke of the actuator and does not indicate the inherent characteristics of the mechanization.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date
Prepared 4/20/79

TEST - Static Threshold - Condition 1




0.1 Hz Ramp Input

Scale: Input = 0.0002 v/div

$X_{out}$ = 0.00003 in/div

t = 2 div/sec

FIGURE 6 Static Threshold - Condition 1

TABLE 2

STATIC THRESHOLD

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 4/18/79

TEST ITEM - Grumman - Bertea Unit
Configuration A

TEST - STATIC THRESHOLD

| Test Condition | Input Volts | Static Threshold: % of Max Input | Static Threshold: % of $E_v$ Max |
|---|---|---|---|
| 1 | 0.022 | 0.11 | 14.30 |
| 2 | 0.026 | 0.13 | 16.91 |
| 3 | 0.036 | 0.18 | 23.41 |
| 4 | 0.028 | 0.14 | 18.21 |
| 5 | 0.034 | 0.17 | 22.11 |
| 6 | 0.036 | 0.18 | 23.41 |
| 7 | 0.024 | 0.17 | 15.61 |
| 8 | 0.026 | 0.13 | 16.91 |
| 9 | 0.036 | 0.18 | 23.41 |
| 10 | 0.032 | 0.16 | 20.81 |
| 11 | 0.026 | 0.13 | 16.91 |

3.5.2.2 Dynamic Threshold

Figure 7 shows the data recorded in establishing the dynamic threshold for Condition 1. A 14 Hz sine wave input was used to drive the actuator. This frequency was .5 of the bandpass frequency at which a $-90^{o}$ phase angle occurs. Note that on Figure 7 the input amplitude of the driving frequency was gradually increased with increasing time. On the bottom trace, the start of the actuator response to the input signal is quite apparent.

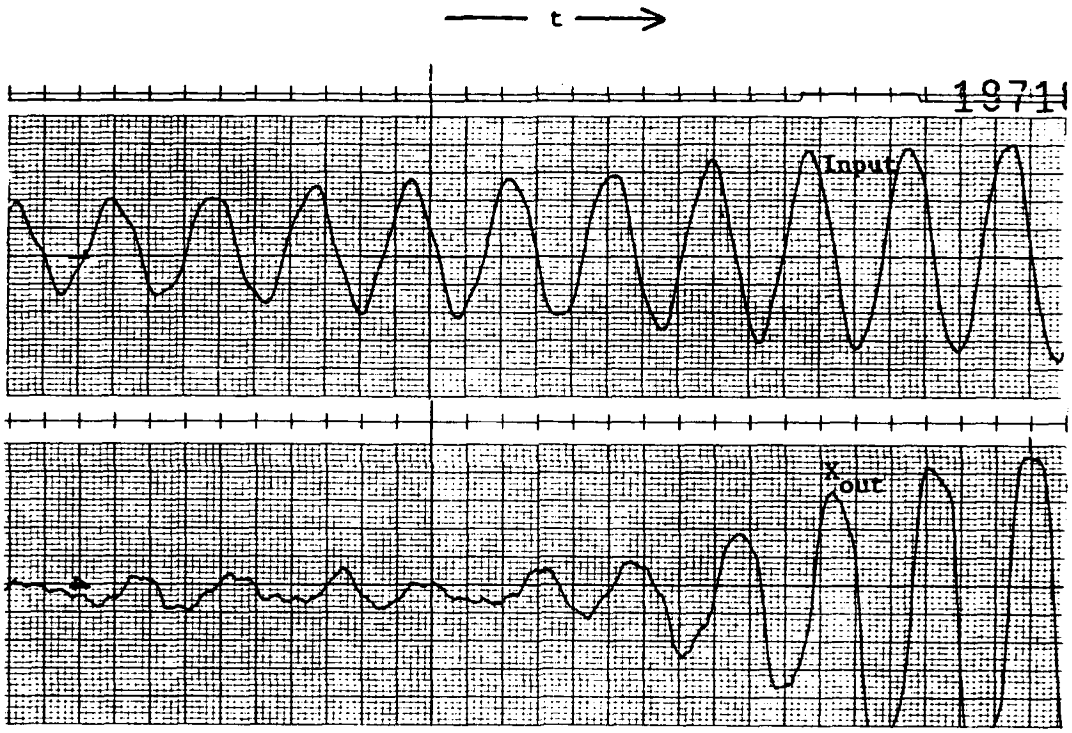
Table 3 shows the dynamic threshold measurements for Conditions 1 through 11. In comparison to the static threshold, the dynamic threshold varies from being slightly greater to considerably greater than the static threshold. Note that for test Condition 3 with two channels electrically failed, the dynamic threshold measured as 94.79% of the input to create maximum flow from the servovalve of one channel. This implies that almost full error current to the servovalves is required to cause the common output of the control channels to move under this test condition. The threshold values expressed in terms of the "% of the Max Input" for full actuator position appear much lower. However, the threshold in terms of the saturated valve input level indicates (as did the static threshold results) that the force sharing mechanization with low pressure gain valves can exhibit high relative threshold levels. Note that the highest values of threshold resulted from test Conditions 2, 3, 4, 5 and 11. These test conditions all have one or more channels failed either electrically or hydraulically.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date
Prepared 4/23/79

TEST - Dynamic Threshold - Condition 1




14.0 Hz Sine Wave Input

Scale: Input = 0.005 v/div
$X_{out}$ = 0.00007 in/div
t = 200 div/sec

FIGURE 7 Dynamic Threshold - Condition 1

TABLE 3

Dynamic Threshold

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 4/18/79

TEST ITEM - Grumman - Bertea Unit
Configuration A

TEST - DYNAMIC THRESHOLD

| Test Condition | Input Volts | Dynamic Threshold % of Max Input | % of $E_v$ Max |
|---|---|---|---|
| 1 | 0.035 | 0.18 | 22.76 |
| 2 | 0.135 | 0.68 | 87.78 |
| 3 | 0.145 | 0.73 | 94.79 |
| 4 | 0.110 | 0.55 | 71.52 |
| 5 | 0.110 | 0.55 | 71.52 |
| 6 | 0.052 | 0.26 | 33.81 |
| 7 | 0.060 | 0.30 | 39.01 |
| 8 | 0.062 | 0.31 | 40.31 |
| 9 | 0.070 | 0.35 | 45.51 |
| 10 | 0.070 | 0.35 | 45.51 |
| 11 | 0.115 | 0.575 | 74.77 |

3.5.2.3 Frequency Response

Figure 8 shows the frequency response recorded for the Condition 1 frequency response measurements. The response for all test conditions resembled the Condition 1 response in terms of lack of peaking and the roll-off slopes. Zero Db on Figure 7 corresponds to an input amplitude of 4% of that required for maximum actuator output stroke. The test input level met the criteria of not producing over the recorded frequency range observable output waveform distortion due to threshold or saturation effects.

Table 4 lists the frequency response for Conditions 1 through 11 in terms of the frequencies at which the $-90^{o}$ phase angle and the -3 Db amplitude ratio point occurred for each test condition. Note that for all test conditions, the frequency associated with the -3 Db amplitude ratio remained relatively constant. Condition 3, with two channels failed electrically, reduced the -3 Db response to 15 Hz from the "no failure" Condition 1 response frequency of 19.5 Hz. This was the lowest response frequency measured for any of the test conditions. The variation of the $-90^{o}$ phase shift frequency followed the minor variations in -3 Db amplitude ratio frequency. Condition 10, with one channel of hydraulic pressure reduced to 2000 psi, exhibited the highest frequency corresponding to $-90^{o}$ phase shift.

The frequency response did not degrade from the base line condition 1 when operated with input offsets (Conditions 6, 7, 8 and 9). This was not anticipated since (for Configuration A) the equalizer feedback was disabled and some frequency response degradation due to the offset related force fighting was anticipated.

TABLE 4

Frequency Response

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 4/18/79

TEST ITEM - Grumman - Bertea Unit
Configuration A

TEST - FREQUENCY RESPONSE

| Test Condition | Output 4% Full Scale -3 Db Hz | Output 4% Full Scale $-90^{o}$ Hz |
|---|---|---|
| 1 | 19.5 | 36.0 |
| 2 | 17.5 | 33.0 |
| 3 | 15.0 | 29.0 |
| 4 | 18.0 | 33.5 |
| 5 | 15.5 | 27.0 |
| 6 | 19.0 | 34.0 |
| 7 | 20.0 | 34.0 |
| 8 | 19.0 | 33.0 |
| 9 | 19.0 | 32.5 |
| 10 | 19.0 | 45.5 |
| 11 | 17.0 | 33.5 |

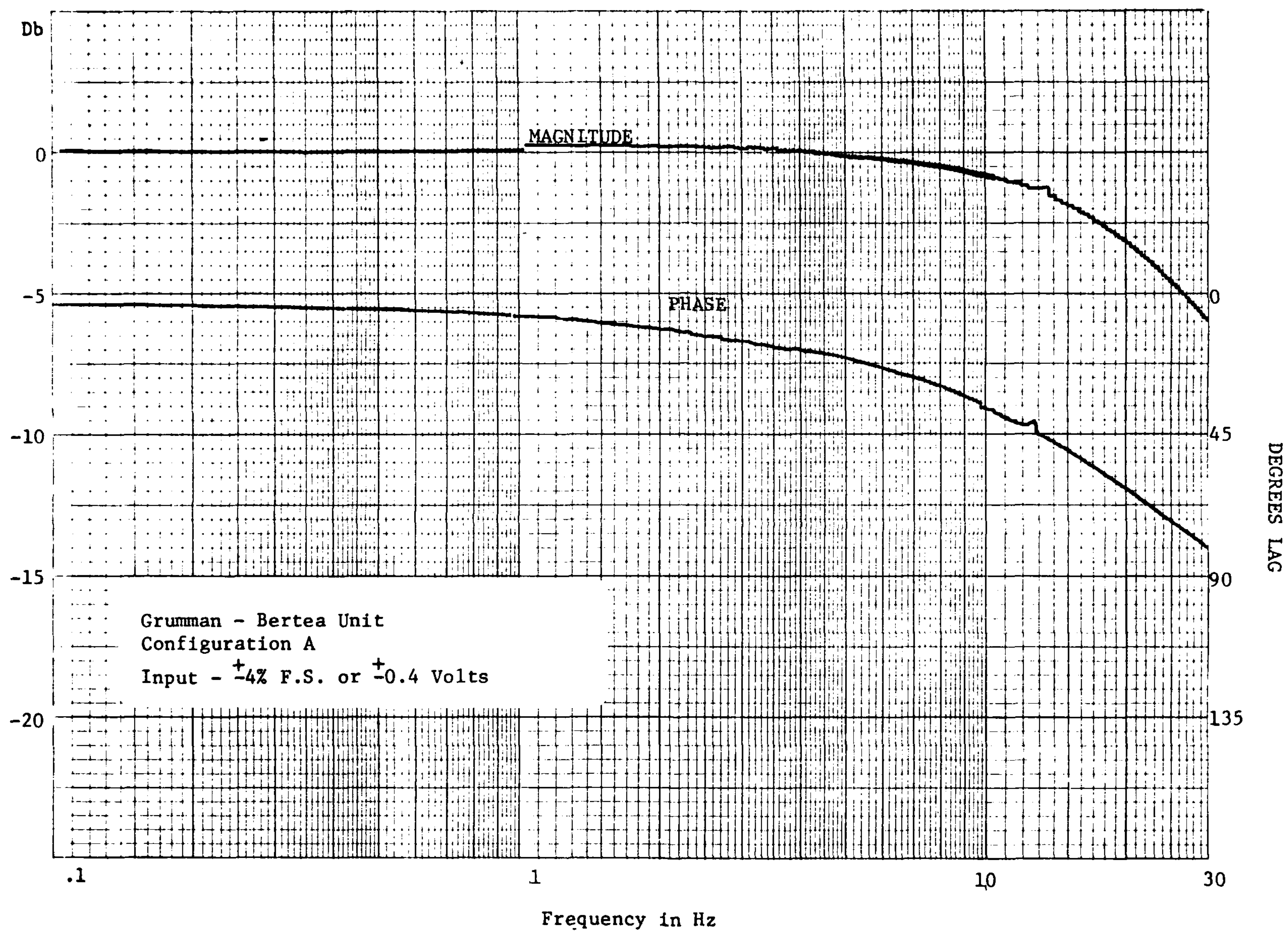



FIGURE 8 Frequency Response - Condition 1

### 3.5.2.4 Distortion

Table 5 lists the harmonic distortion measurements for test Conditions 1 through 11. For each test condition, 3 distortion measurements are listed, corresponding to 5 Hz, 10 Hz and 20 Hz. The input level used when making the measurements was 4% of the full scale input level (the same as that used in obtaining the frequency response plots). Since some distortion can be attributed to noise pickup on the instrumentation lines, the table lists the distortion in terms of the % change from the baseline value obtained for operating Condition 1. The baseline distortion values are below 4% distortion for all three test frequencies and indicate a distortion level that would be difficult to detect visually on a sinusoidal signal.

The measured distortion increased from the baseline values for test Conditions 2 through 6. However, the percent distortion increase for the worst case was only an increase in distortion of 2.5% (for Condition 3 @ 10 Hz). For the low frequency (5 Hz) test with operating conditions 7 through 11, the distortion was less than that of the baseline test Condition 1.

The distortion characteristics, like the frequency response, remained commendably constant for the operating conditions 2 through 11. The base line distortion was quite low for the test condition of 4% input and indicates good fidelity of the signal transmission from electrical command to position output of the mechanization.

TABLE 5

Distortion

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 4/19/79

TEST ITEM - Grumman - Bertea Unit
Configuration A

TEST - DISTORTION

| Test Condition | Change of % distortion from baseline value | | |
|---|---|---|---|
| | % @ 5 Hz | % @ 10 Hz | % @ 20 Hz |
| 1 | Baseline Value* | Baseline Value** | Baseline Value*** |
| 2 | 0.49 | 0.60 | 0.30 |
| 3 | 1.50 | 2.50 | 1.70 |
| 4 | 0.20 | 0.60 | 0.30 |
| 5 | 0.40 | 1.50 | 0.30 |
| 6 | 0.80 | -0.20 | 0.10 |
| 7 | -0.60 | 0 | 0 |
| 8 | -0.30 | 0.10 | 0.50 |
| 9 | -0.50 | 0.10 | -0.20 |
| 10 | -0.50 | -0.20 | 0.19 |
| 11 | -0.50 | -0.30 | 0.40 |

*2.84% **2.86% ***3.66%

3.5.2.5 Hysteresis

Figure 9 shows the data recorded for measuring the hysteresis of the mechanization for Condition 1. The input level used was ±1% of the input for full actuator position. As shown on Figure 9, the hysteresis loop resembles that of a device with static friction in the control path.

Table 6 lists the hysteresis measured for the test Conditions 1 through 11 in terms of the actuator full scale input and in terms of the input required to generate full flow from the servovalve. Note that the hysteresis in terms of the input for maximum actuator stroke is less than .25% for any test condition. The hysteresis in terms of the input required to generate maximum flow from the servovalve is much larger, with the lowest hysteresis being 12.4% for the baseline Condition 1. For Condition 3, (with two channels failed electrically), the hysteresis measured 23.4% in terms of the input for maximum flow from the servovalve. Condition 5, with two channels failed hydraulically, gave a hysteresis of 27.3%. Both these hysteresis figures are approximately twice the "no failure" Condition 1 hysteresis and would appear to be due to the reduction of the force gain of the mechanization with failure of two channels. Hysteresis of a typical electrohydraulic two stage servovalve is 3 to 4%, a figure considerably lower than that of the demonstrator.

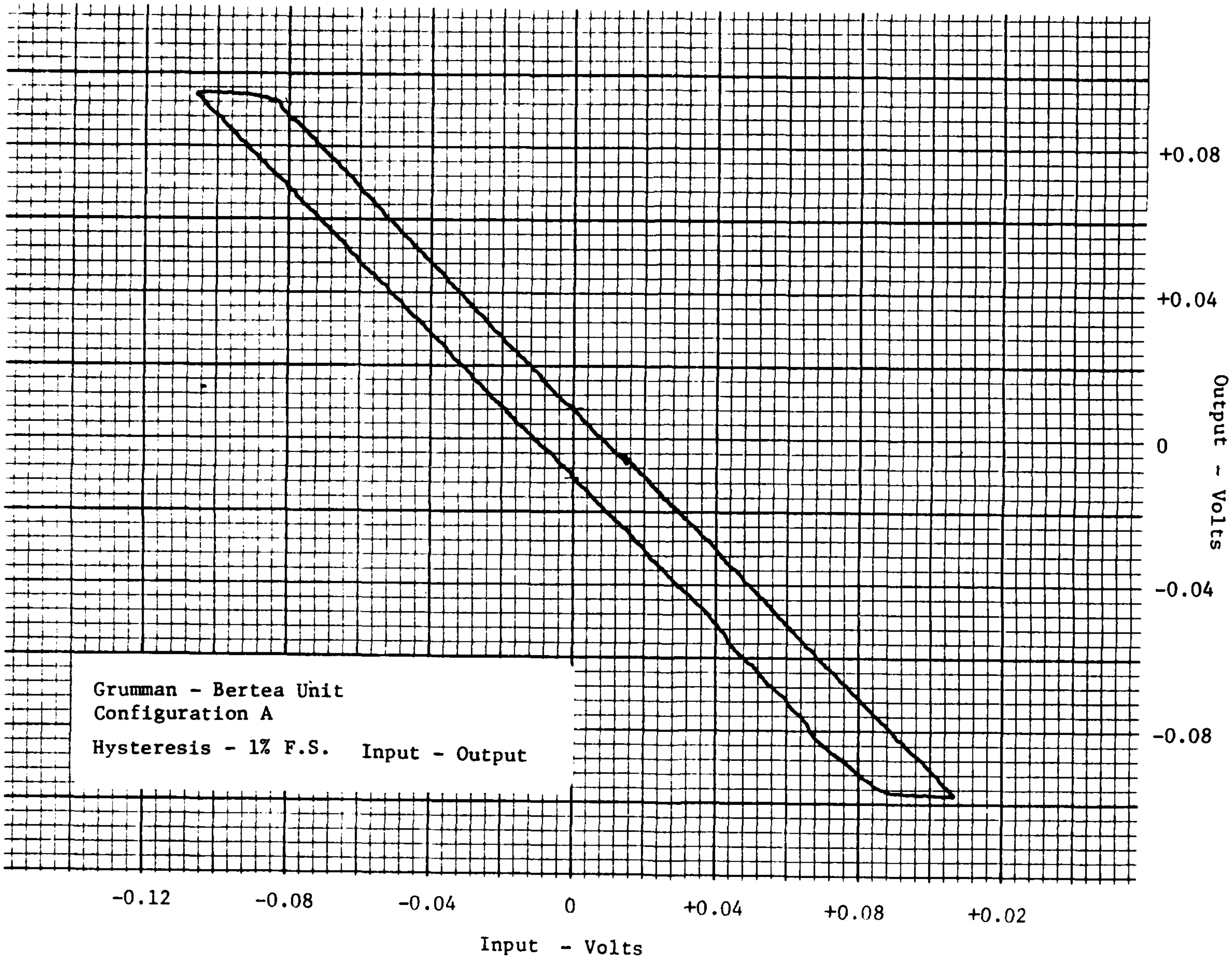



FIGURE 9 Hysteresis - Condition 1

TABLE 6

Hysteresis

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 4/19/79

TEST ITEM - Grumman - Bertea Unit
Configuration A

TEST - HYSTERESIS

| Test Condition | % Full Scale | % of $E_v$ Max |
|---|---|---|
| 1 | .095 | 12.40 |
| 2 | 0.12 | 15.60 |
| 3 | 0.18 | 23.40 |
| 4 | 0.12 | 15.60 |
| 5 | 0.21 | 27.30 |
| 6 | 0.15 | 19.50 |
| 7 | 0.13 | 16.90 |
| 8 | 0.14 | 18.20 |
| 9 | 0.15 | 19.50 |
| 10 | 0.11 | 14.30 |
| 11 | 0.10 | 13.00 |

### 3.5.2.6 Saturation Velocity

Figure 10 shows the data recorded for test Condition 1 in order to determine the saturated velocity of the demonstration actuator output. Both the extend and the retract time traces for a step of 8 volts (applied to the input of the demonstration unit) are shown. This input voltage was large enough to insure that the maximum flow to the actuator was obtained from the servovalves.

Table 7 lists the saturated extend and retract velocities for test Conditions 1 through 11. The trend for the change in the measured velocities with test Conditions 2 through 11 as compared to the test Condition 1 was a velocity decrease. The worst case change for extend and retract motions was an approximate 25% decrease for test Condition 5 (two channels failed hydraulically). This decrease is expected, since the remaining two channels of the demonstrator are forced to move the two failed channels with themselves.

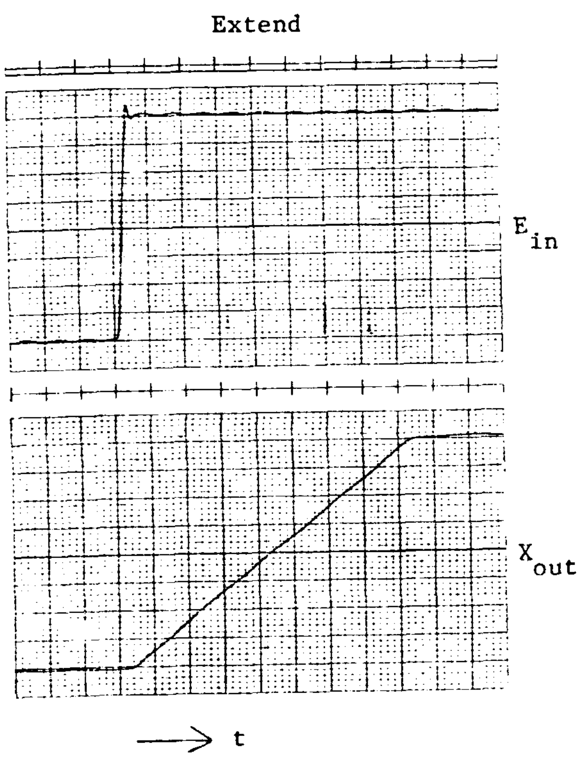
Since hydraulic failures are not actively detected by the demonstrator, the active channels remaining after a hydraulic failure would be required to back drive the failed actuator channels through their depressurized jet pipe servovalves. This creates a reduction of the maximum rate of the actuator mechanization, compared to the no failure operating condition.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date Prepared 4/24/79

TEST - Saturation Velocity - Condition 1




Maximum Amplitude Step Input

Scale: Input = 0.200 v/div
$X_{out}$ = 0.013 in/div
t = 200 div/sec

FIGURE 10 Saturation Velocity - Condition 1

TABLE 7

Saturation Velocity

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 4/19/79

TEST ITEM - Grumman - Bertea Unit
Configuration A

TEST - SATURATION VELOCITY

| Test Condition | Extend - in./sec. | Retract - in./sec. |
|---|---|---|
| 1 | 2.74 | 2.67 |
| 2 | 2.48 | 2.43 |
| 3 | 2.27 | 2.22 |
| 4 | 2.48 | 2.43 |
| 5 | 2.01 | 2.05 |
| 6 | 2.74 | 2.70 |
| 7 | 2.67 | 2.81 |
| 8 | 2.67 | 2.74 |
| 9 | 2.54 | 2.74 |
| 10 | 2.37 | 2.37 |
| 11 | 2.37 | 2.37 |

### 3.5.2.7 Linearity

Figure 11 shows the actuator output linearity measured for Condition 1. The linearity of the mechanization is primarily determined by the feedback transducers associated with each control channel and the loop gains (position) of the individual channels. The linearity measured for all the operating conditions was essentially the same as that shown on Figure 11 and within 1% full scale.

### 3.5.2.8 Step Response

Figures 12 through 17 show the extend and retract step response measurements for Conditions 1 through 11. The input level for these measurements was 4% of the input for maximum actuator position. This level, since it was a step input, was twice that required for a saturation of the servovalve. Therefore, until the actuator moved 50% of the total movement in response to the command step, the servovalve was saturated and the actuator moved at a saturation rate. The remaining 50% of the movement as shown on Figures 12 through 17 is unsaturated and indicates the transient response of the mechanization.

The measured response is consistent with the frequency response measurements. The step response results show no overshoot and no ringing for any of the test conditions. The step response resembles that of a second order system with a damping ratio of approximately 1.

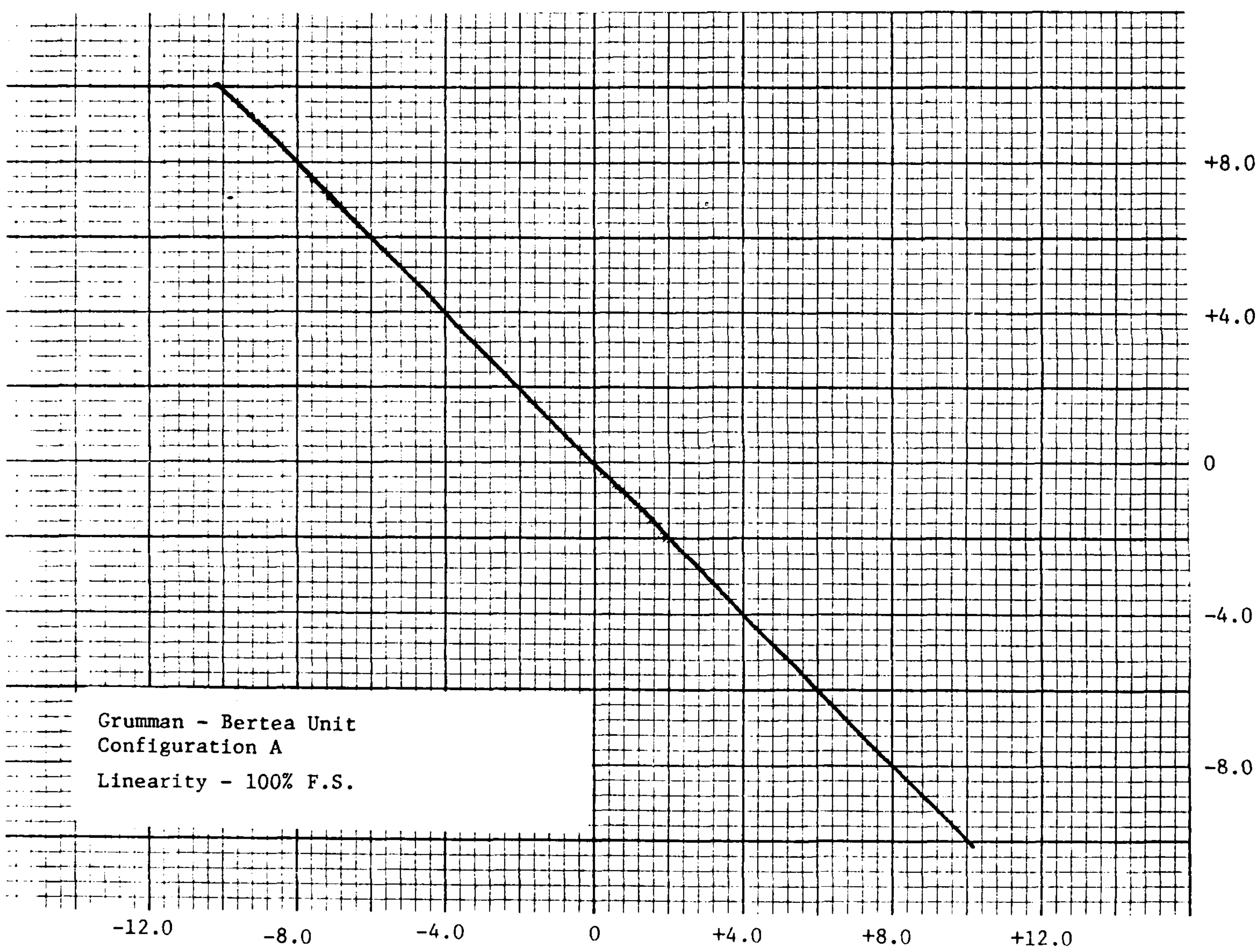



FIGURE 11 Linearity - Condition 1

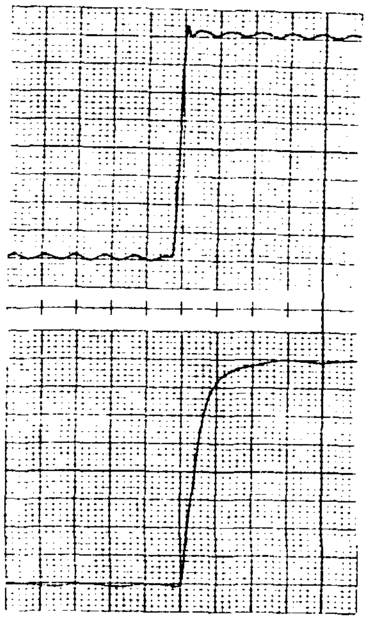
DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

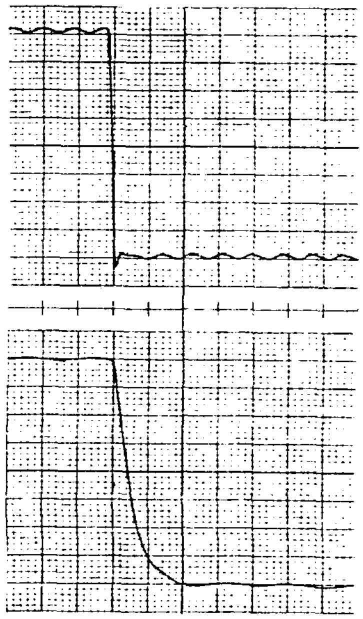
TEST - Step Response - Condition 1 & 2

Date
Prepared 4/30/79

Extend



Retract



$E_{in}$

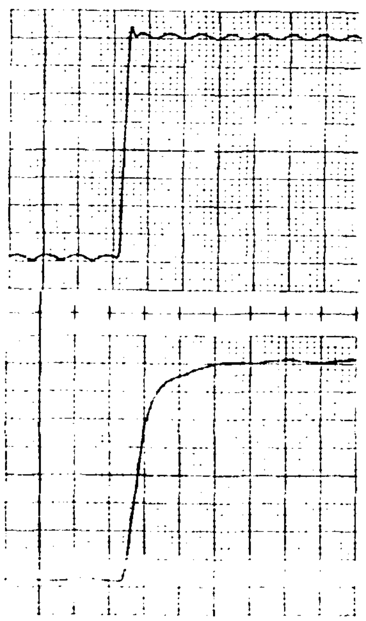
Condition 1
4% F.S. Output

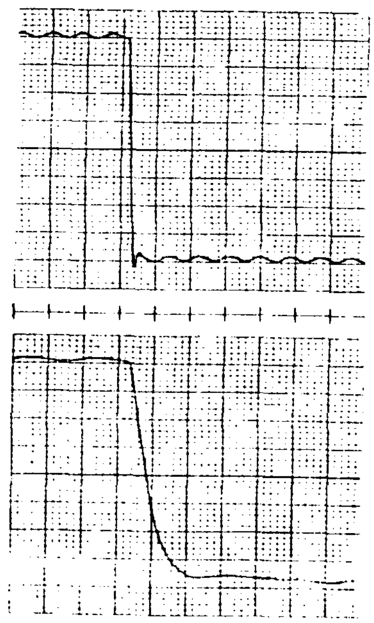
$X_{out}$

→ t

Scales:
$E_{in}$ = 0.020 v/div
$X_{out}$ = 0.00133 in/div
t = 200 div/sec

→ t





$E_{in}$

Condition 2
4% F.S. Output

$X_{out}$

FIGURE 12 Step Response - Condition 1 & 2

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date Prepared 4/30/79

TEST - Step Response - Conditions 3 & 4

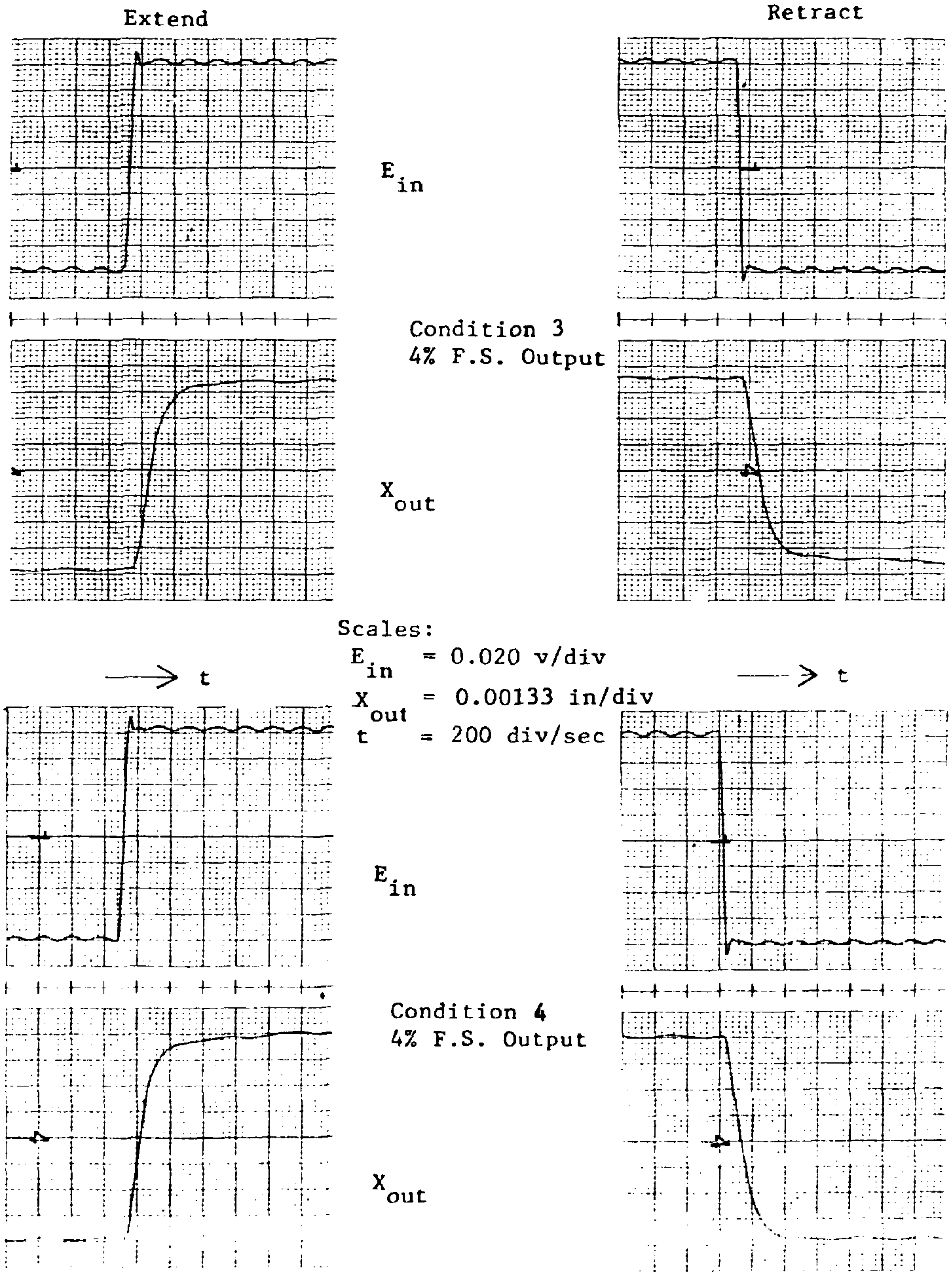



FIGURE 13 Step Response - Condition 3 & 4

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date
Prepared 4/30/79

TEST - Step Response - Conditions 5 & 6

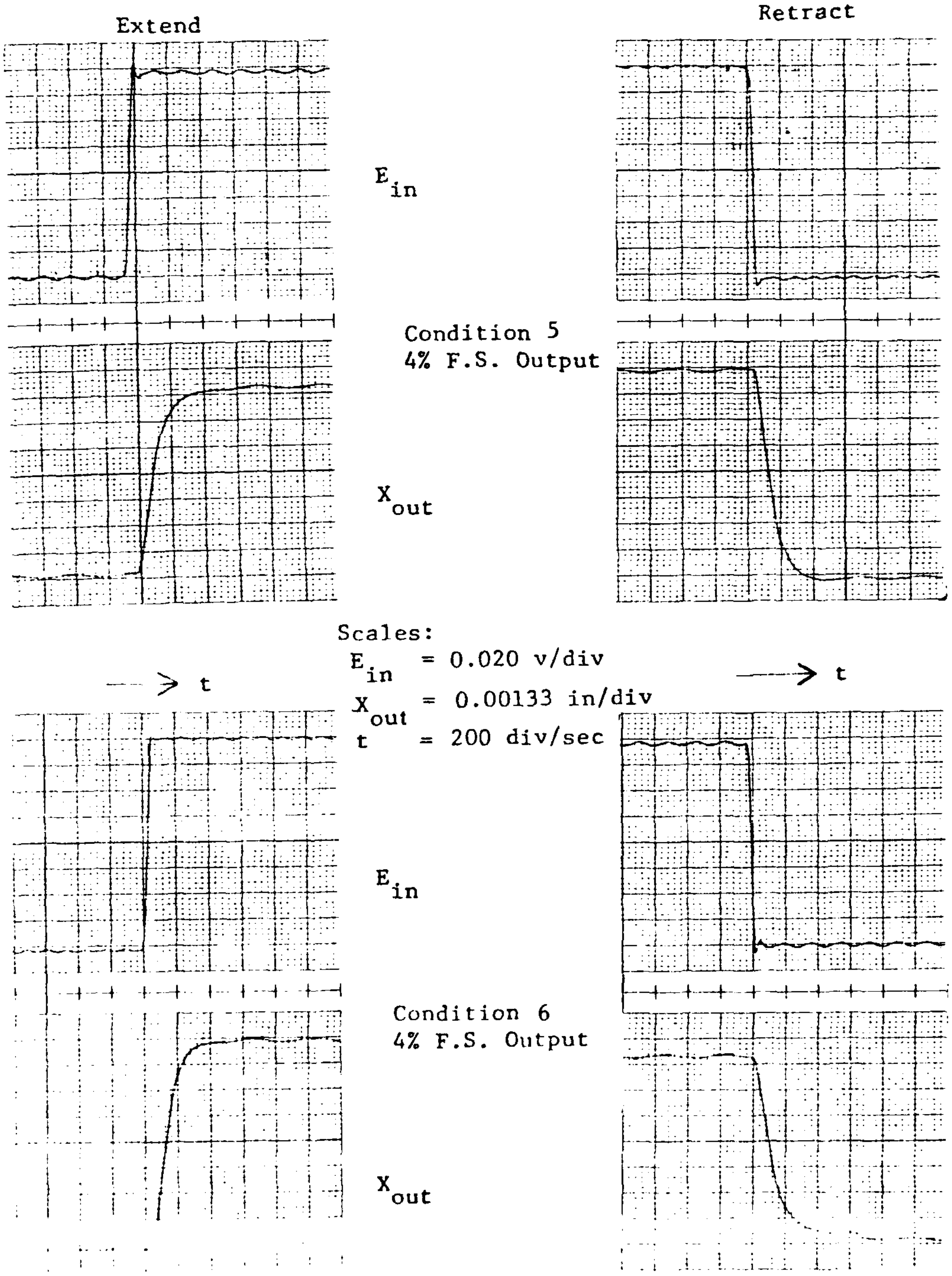



FIGURE 14 Step Response - Condition 5 & 6

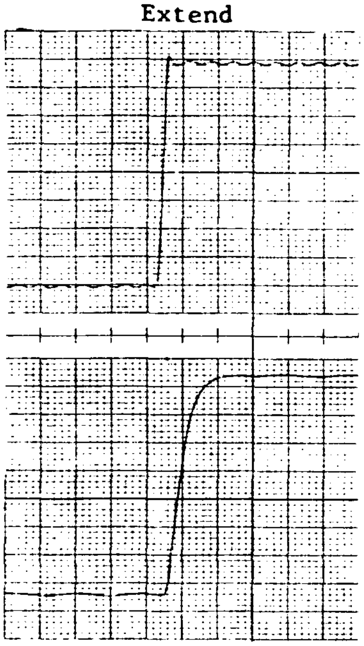
DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM – Grumman - Bertea Unit
Configuration A

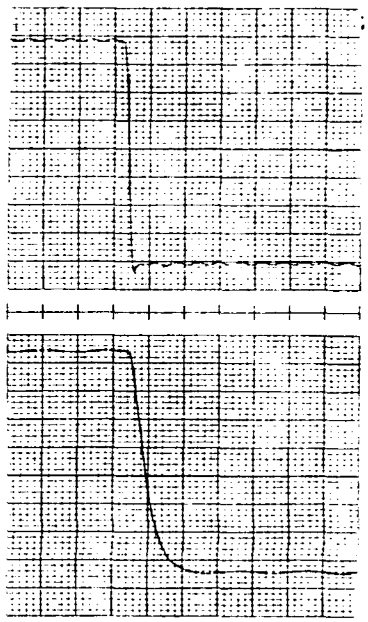
TEST – Step Response - Condition 7 & 8

Date
Prepared 4/30/79

Extend



Retract



$E_{in}$

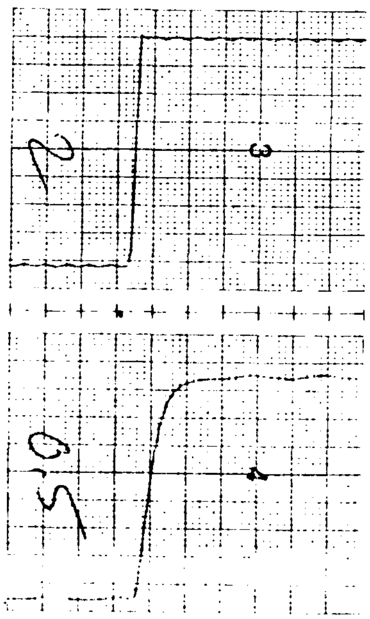
Condition 7
4% F.S. Output

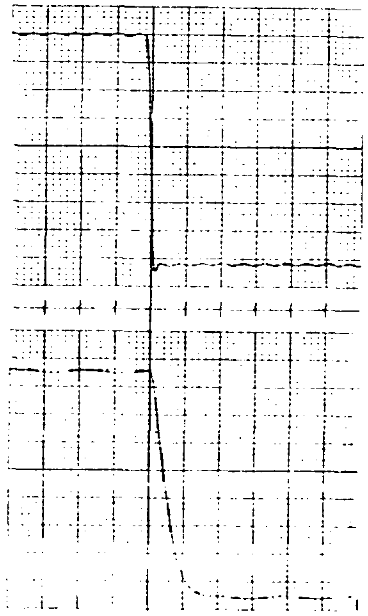
$X_{out}$

→ t

Scales:
$E_{in}$ = 0.020 v/div
$X_{out}$ = 0.00133 in/div
t = 200 div/sec

→ t





$E_{in}$

Condition 8
4% F.S. Output

$X_{out}$

FIGURE 15 Step Response - Conditions 7 & 8

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date
Prepared 4/30/79

TEST - Step Response - Condition 9 & 10

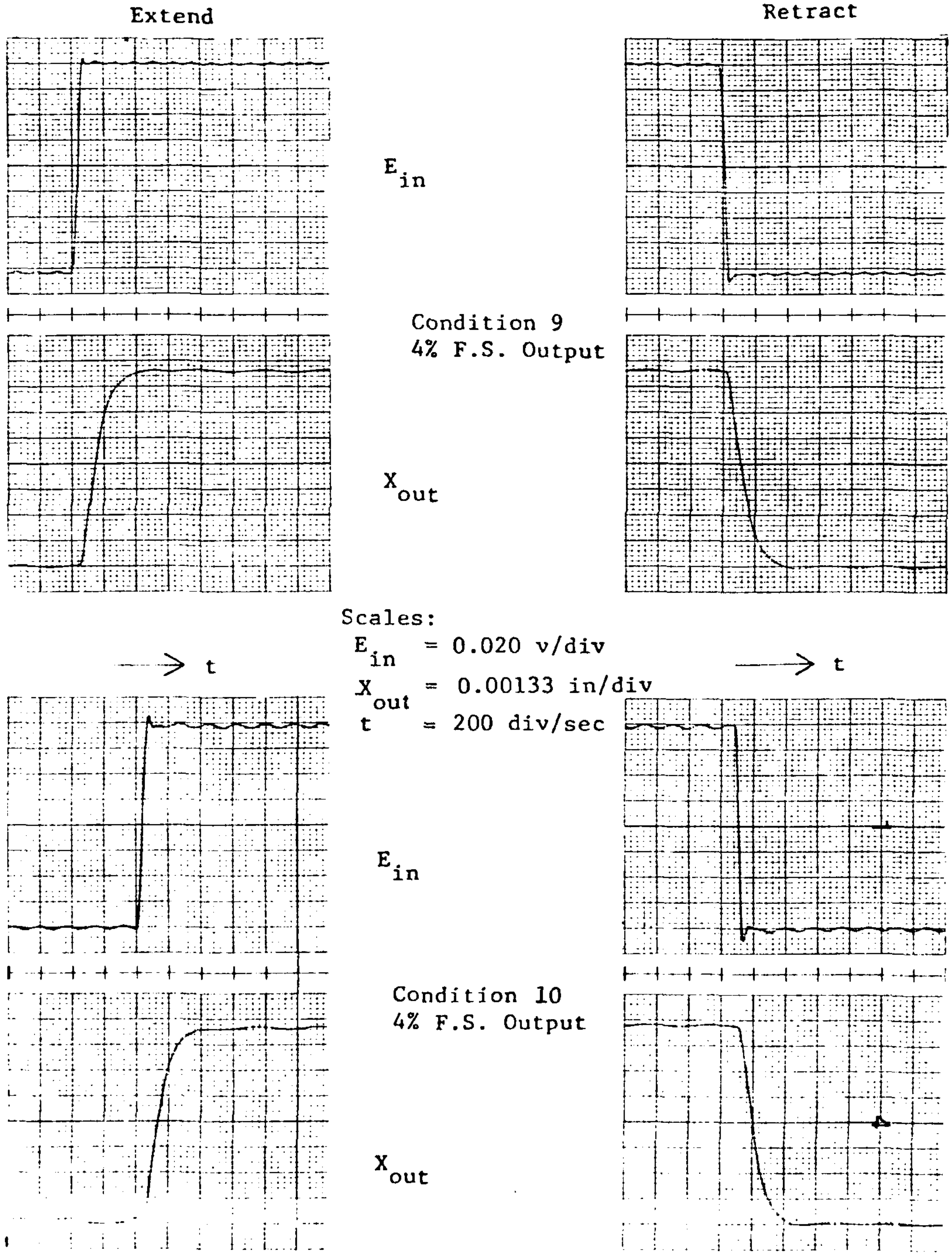



FIGURE 16 Step Response - Conditions 9 & 10

DYNAMIC CONTROLS, INC.
Test Data

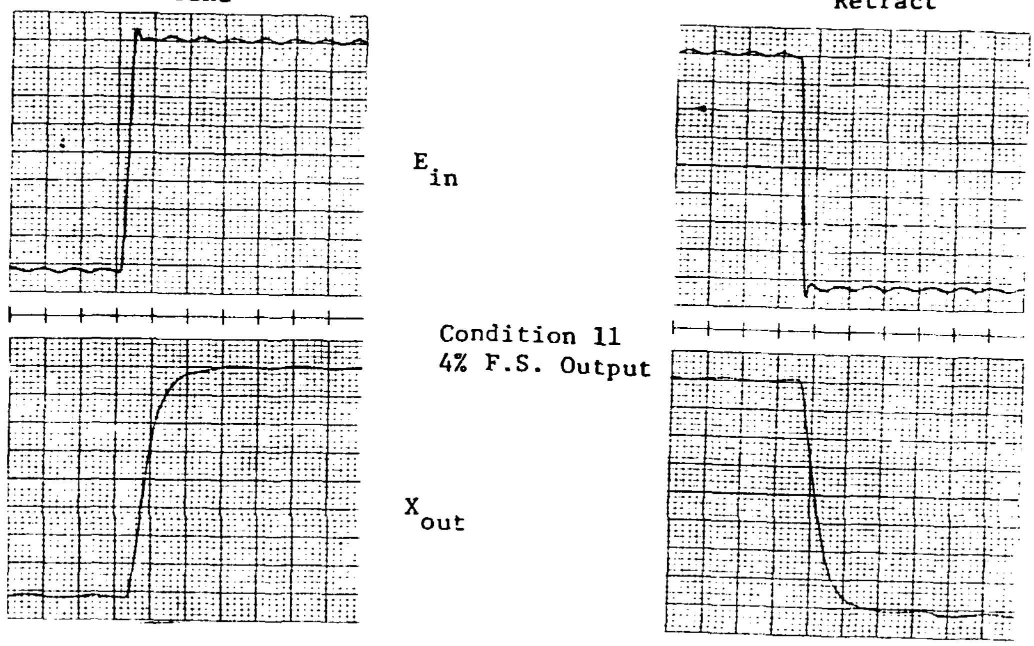
TEST ITEM - Grumman - Bertea Unit
Configuration A

TEST - Step Response - Condition 11

Date
Prepared 4/30/79

Extend

Retract




→ t

Scales:
$E_{in}$ = 0.020 v/div
$X_{out}$ = 0.00133 in/div
t = 200 div/sec

→ t

FIGURE 17 Step Response - Condition 11

### 3.5.3 Failure Transients

Test Conditions 12 through 27 were used to establish the failure transient characteristics of Configuration A. The test results and te t conditions are arranged in the following order:

| TEST | Test Conditions |
|---|---|
| Electrical Input Loss Transient | 12, 13, 14, 15 |
| Electrical Hardover Input Transient (with actuator initially at rest) | 16, 17, 18, 19, 20, 21 |
| Electrical Hardover Input Transient (with actuator initially cycling) | 22, 23 |
| Simultaneous Hardover Input Transient | 24, 25 |
| Slowover Electrical Input Transient | 26, 27 |

The test results in the following sub-sections are presented as listed above.

#### 3.5.3.1 Electrical Input Loss Transient

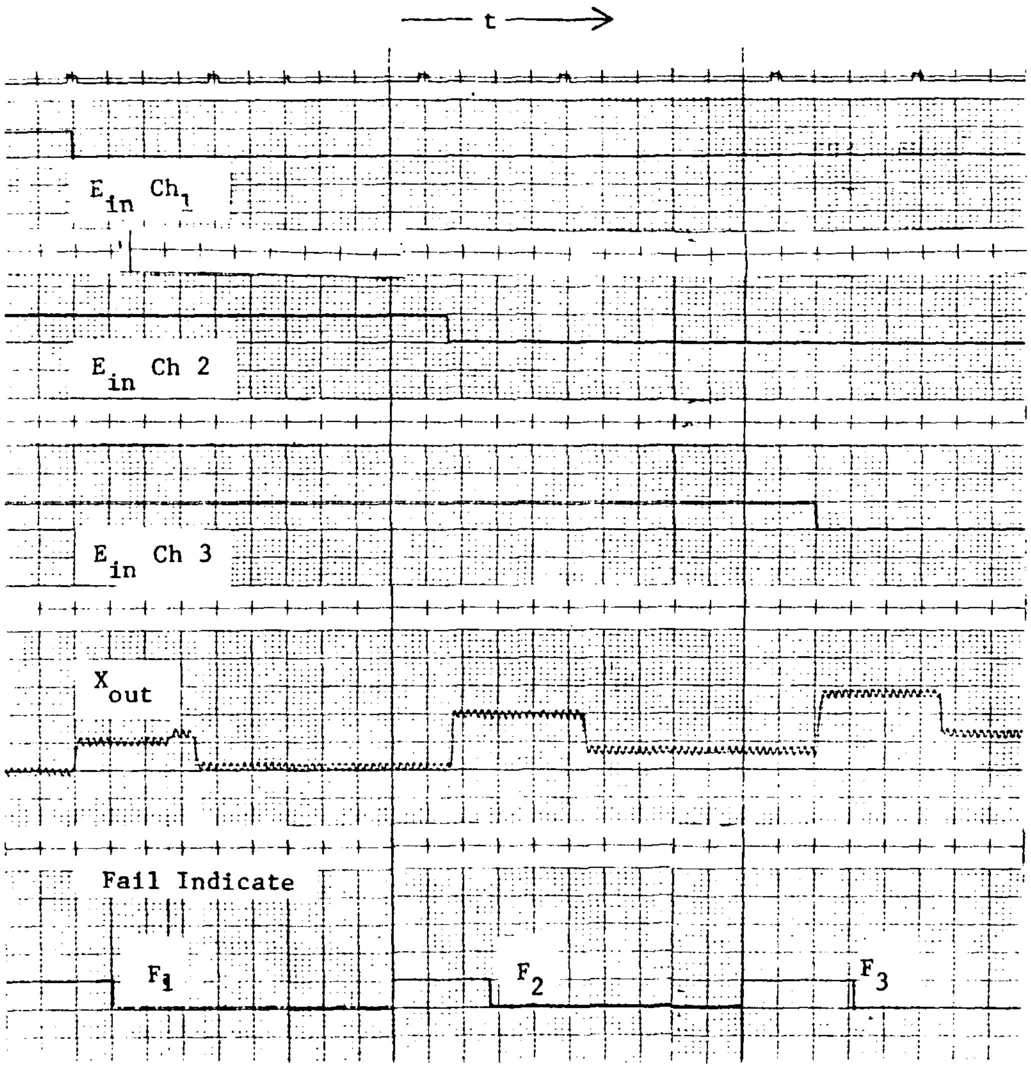
Figure 18 shows the effect of a sequential channel input loss with the actuator initially commanded to a 50% extend position. Failure of the inputs (a change to 0 input voltage by grounding the input of the particular channel) is displayed on the three data channels of Figure 18. The change of position of the actuator with each injected failure is displayed on the fourth data channel from the top. Activation of the failure removal warning lights is shown on the bottom data channel of Figure 18. The deviation of the actuator position is 0.32% of the total actuator stroke with the first failure. The deviation increased to 0.68% of the total actuator stroke on the last failure. As shown on Figure 18, the time delay of the failure logic for failure removal was .85 seconds for the test evaluation. This time delay setting was the value the demonstrator was delivered with and was not changed for the evaluation tests.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date
Prepared 5/21/79

TEST - Failure Transients - Condition 12




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.0007 in/div
t = 20 div/sec

FIGURE 18 Failure Transients - Condition 12

Figure 19 shows the effect of a sequential channel input loss with the actuator initially commanded to a 50% retract position. The results are similar to the input loss with an initial extend command to the actuator. The deviation of the actuator position is 0.32% of the total actuator stroke for the first and second failures. The deviation for the third failure is 0.79% of the total actuator stroke. The duration of each deviation is approximately .85 secs (the failure removal time delay), after which the actuator returns to nearly its position before the injected failure. The actuator position after failure removal remained closer to the initial commanded position for Figure 19 (with a retract initial position) than for Figure 18 (with an extend initial position).

Figure 20 shows the effect of sequential grounding the inputs to the channels while the actuator is being cycled at 10 Hz. This frequency is one half the -3 Db amplitude frequency for the frequency response of the demonstrator. The amplitude of the actuator motion is $\pm$1.71% of the maximum actuator stroke. This amplitude at the 10 Hz frequency is just below that which would cause the control channels to exhibit rate saturation. From Figure 20, it is apparent that the failure logic does not detect the injected failures and transfer the failed channels from contributing to the output of the demonstrator. Therefore, the failed channels (with a grounded input) tend to oppose being driven by the channels commanded by the 10 Hz input. This has the effect of reducing the output amplitude with each failure injected. For a first failure, the output amplitude is reduced by 36%. For the second failure the output is reduced to 50% of the no failure output. For the third failure, the output is reduced to 14% of the "no failure" output amplitude.

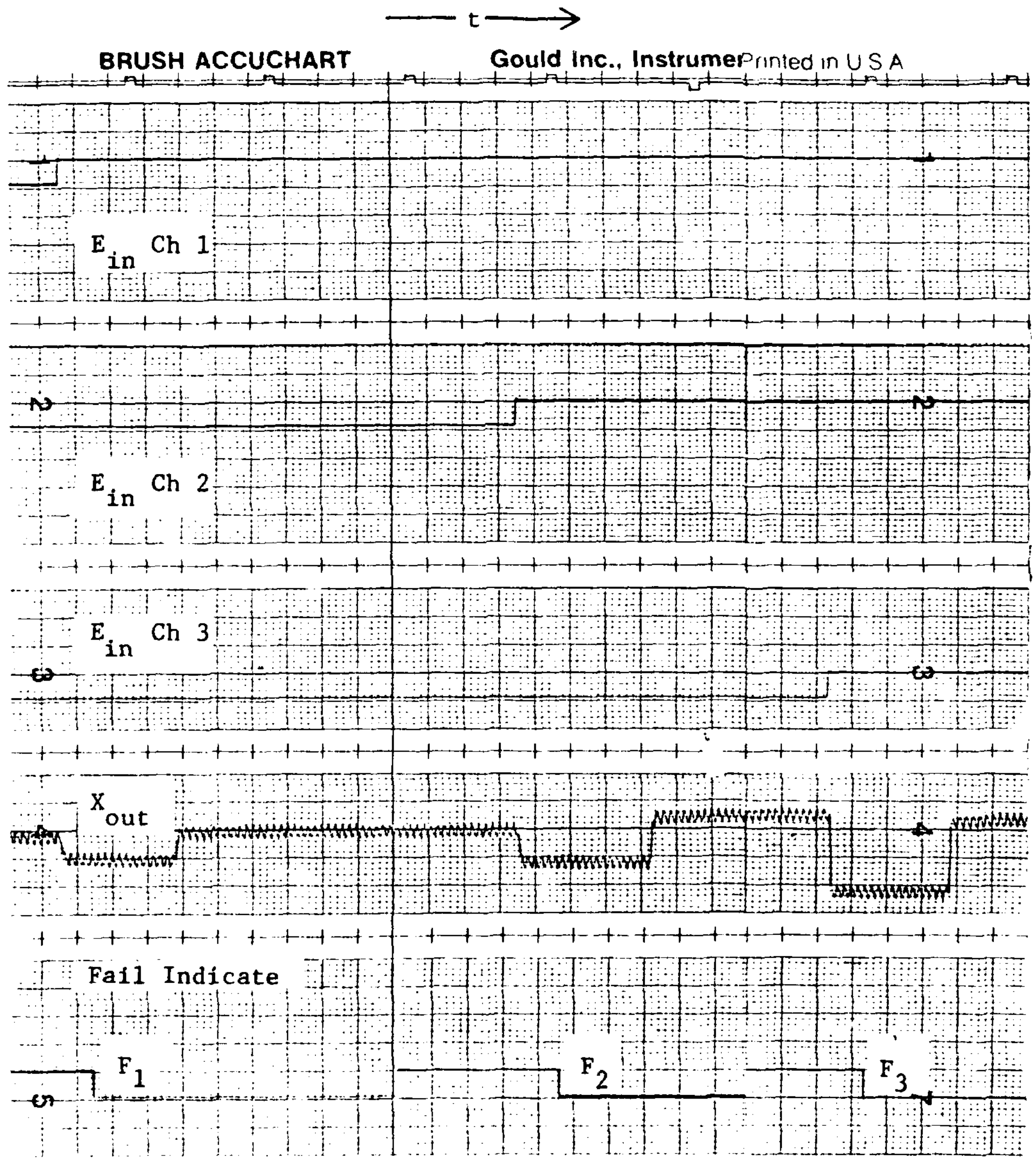
This effect is consistent with the expected characteristics of a force summed mechanization without failure detection.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date
Prepared 5/21/79

TEST - Failure Transients - Condition 13




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.0007 in/div
t = 20 div/sec

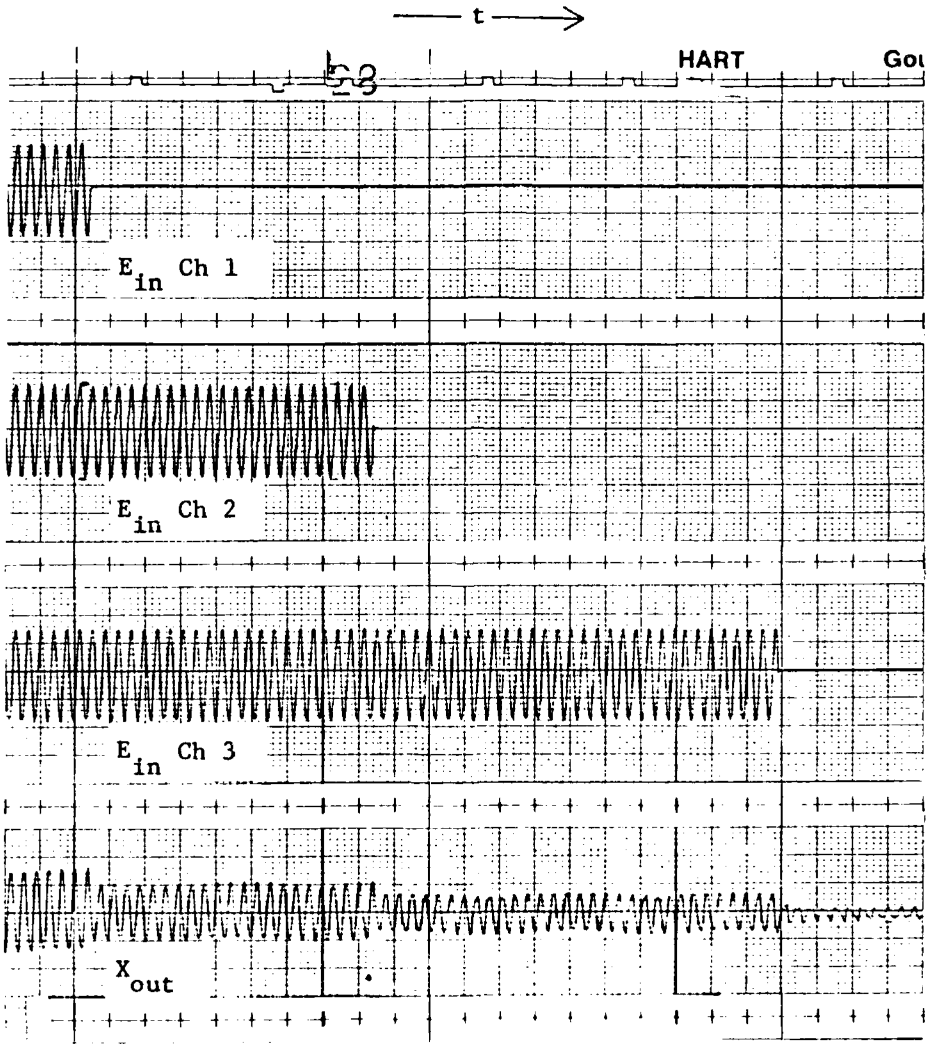
FIGURE 19 Failure Transients - Condition 13

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date
Prepared 5/23/79

TEST - Failure Transients - Condition 14




Scale: $E_{in}$ = 0.050 mv/div

$X_{out}$ = 0.0033 in/div

t = 20 div/sec

FIGURE 20 Failure Transients - Condition 14

Figure 21 shows the effect of simultaneous grounding of two input channels to the demonstrator with the actuator cycling at 10 Hz at an amplitude of $\pm$ 1.98 of the maximum actuator stroke. The effect is similar to that shown on Figure 20. The failures are not detected and the output amplitude of the actuator is reduced to 43% of the "no failure" amplitude. Note that the lack of failure detection at 10 Hz cycling implies that the response characteristics of the failure detection circuits are below that of the control channels being monitored.

#### 3.5.3.2 Hardover Input Transient

Figure 22 shows the effect of a 10 volt step input applied sequentially to channels 1, 2 and 3. The output deviation of the actuator is shown on data channel 4 from the top of the figure. Activation of the failure warning lights is shown on the bottom data channel. The actuator output deviation for the first two injected failures is 0.58% of the total actuator stroke of 1.334 inches). The actuator output deviation for the third injected failure is 0.79% of the total actuator stroke.

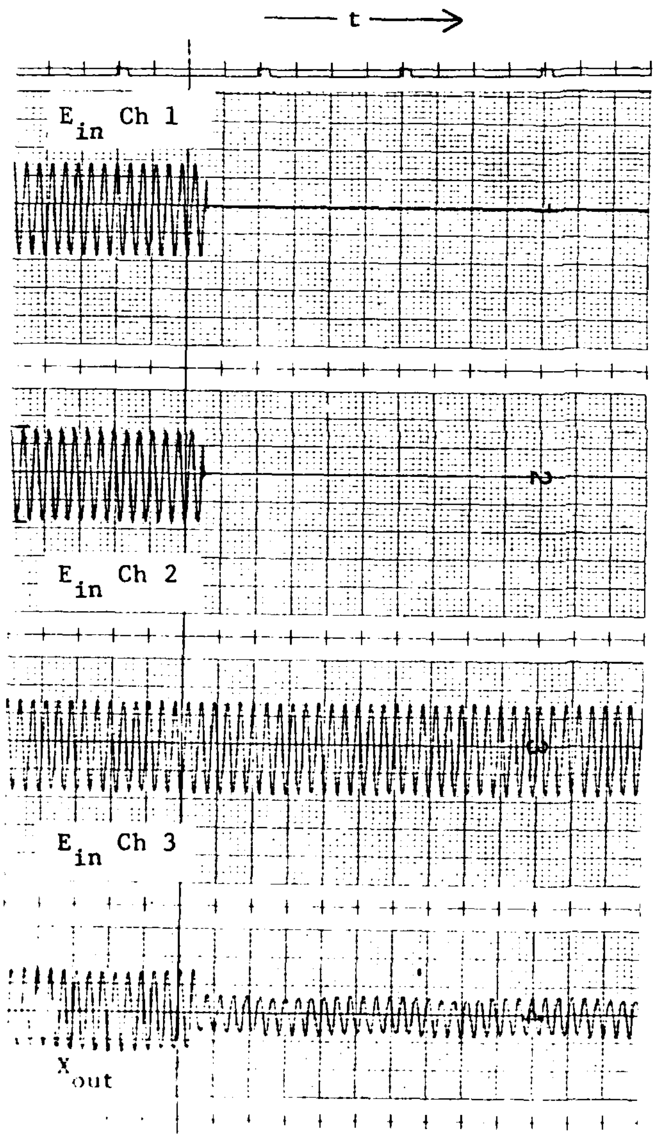
Duration of the actuator deviation for the first failure is 1.25 seconds. This is longer than the .85 second time delay observed for the loss of input and other hardover input transient tests. The increased time delay is probably due to a minor anomoly in the failure detection circuit, since as can be observed for the Fail Indicate data channel, the $F_1$ fail voltage cycles once before the failed channel is transferred out. The second and third failures do indicate that the normal .85 second time delay before failure removal is operating.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date
Prepared 5/23/79

TEST - Failure Transients - Condition 15




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.0033 in/div
t = 20 div/sec

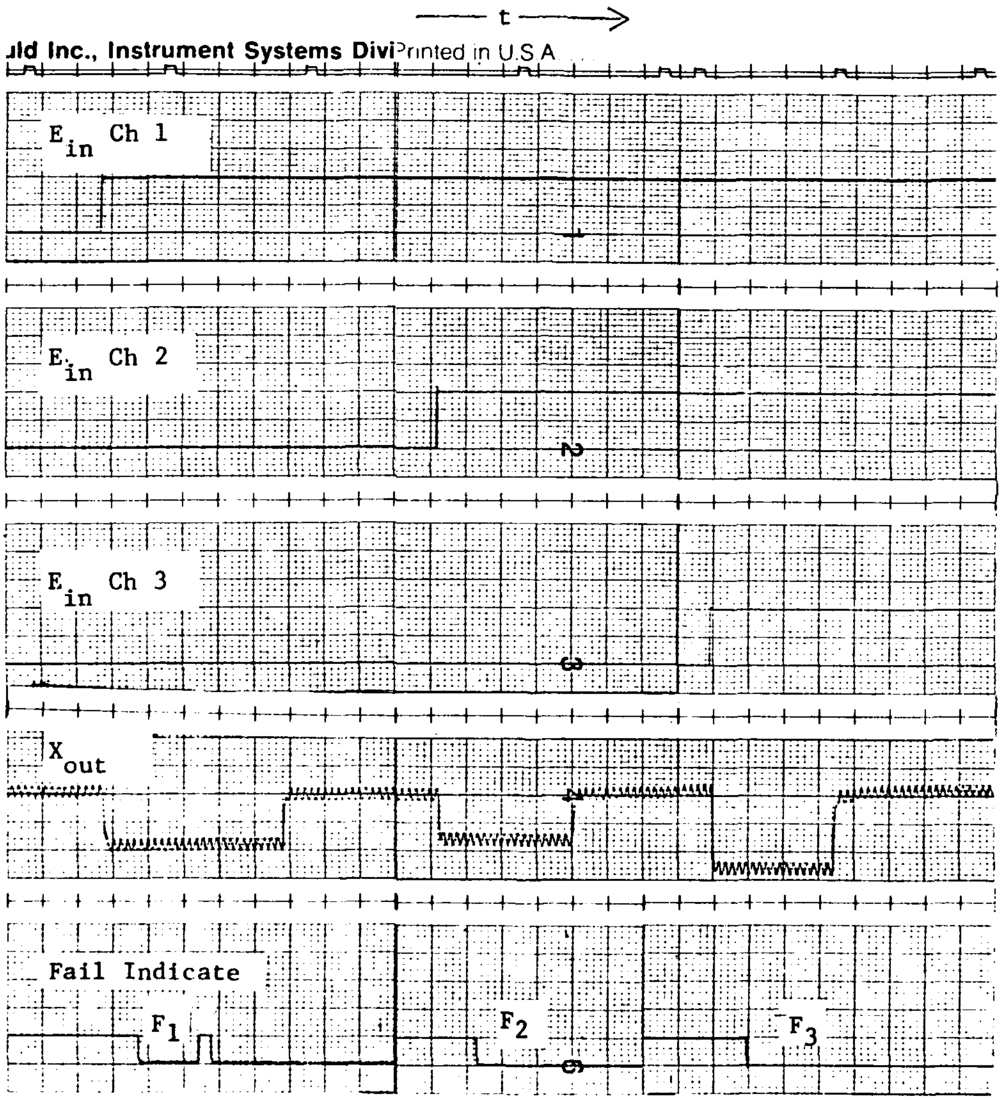
FIGURE 21 Failure Transients - Condition 15

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date Prepared 5/9/79

TEST - Failure Transients - Condition 16




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.0007 in/div
t = 20 div/sec

FIGURE 22 Failure Transients - Condition 16

The deviation occurring with the hardover inputs is determined by the amount of actuator motion required to cause the "good" channels to oppose the "failed" channel. Since the fourth channel is brought up to 100% force capability upon a first failure, there are two "good" channels to oppose a "failed" channel for the first two injected failures. Upon a third failure, the actuator moves until the remaining "good" channel offsets the "failed" channel. The deviation is greater than that for the first and second channel failures since only one "good" channel is available for offsetting the failed channel. As shown on Figure 22, the third failure is apparently detected and the failed channel switched out, allowing channel four to recenter the actuator. If no failure detection for a third failure was used, the actuator output would remain at the 0.79% of total stroke deflection.

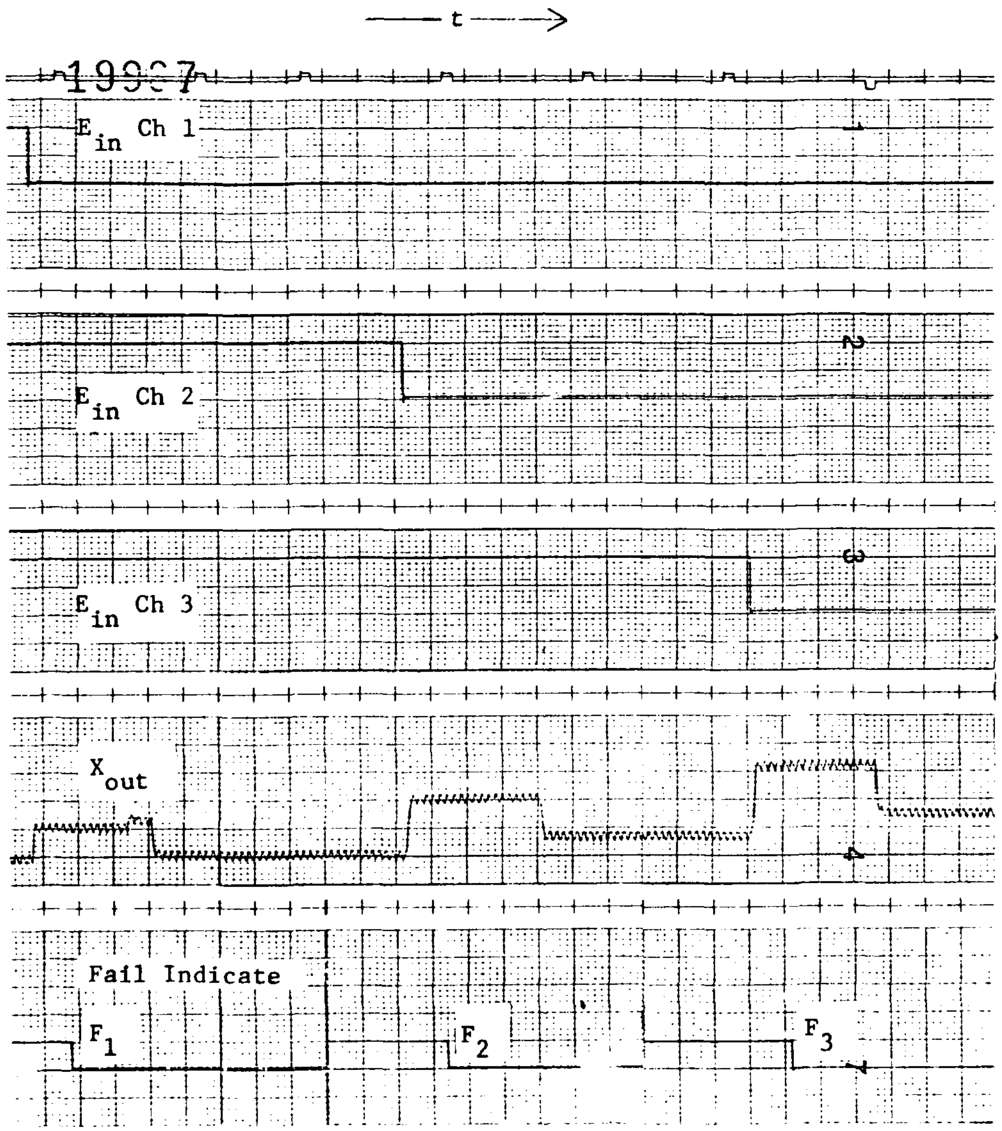
The hardover input was not applied to channel four as a third failure input. With only two operating channels to use for failure voting, determining which channel is "good" and which channel is "bad" is not feasible. If the failure detection depressurized the "good" channel and not the failed channel, the failed channel would command the actuator in response to the particular failure. This means in case of the particular mechanization tested, channel 3 would be depressurized and the channel four (subjected to a hardover input) would be allowed to drive the actuator output hardover. This is not an inherent characteristic of the force sharing mechanization, since preventing the failure logic from depressurizing any channel after two failures have occurred would eliminate the possibility of a hardover output.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date
Prepared 5/10/79

TEST - Failure Transients - Condition 17




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.000
t = 20 div/sec

FIGURE 23 Failure Transients - Condition 17

### 3.5.3.3 Simultaneous Hardover Input Failure Transient

Figure 30 shows the effect of the simultaneous application of hardover inputs to channels 1 and 2. This test was conducted to evaluate the effect of simultaneous input failures which, although statistically not very probable, can happen with a Fly-By-Wire control system. The time window in which sequential failures appear as being simultaneous would be the time lapse from the failure application until the failure logic activates the failure indicate lights (as shown on Figures 16 through 23). This time window is .25 seconds wide.

Figure 30 shows the actuator responding to the step inputs by moving to a new position, displaced 1.95% of the maximum stroke from null. This position is a limited displacement change, which was unanticipated. With the two channels (3 and 4) opposing channels 1 and 2 with a hardover input, channel 4 is force limited to 50% of the force capability of the other three channels. This would theoretically prevent channels 3 and 4 (without the hardover input) from force balancing the failed channels after a given actuator displacement and would allow the actuator to go hardover.

Figure 31 shows the effect of applying a hardover input simultaneously to channels 1 and 2 with the actuator cycling at 10 Hz at the maximum unsaturated amplitude available. Upon application of the hardover input, the actuator output stops responding to the 10 Hz input signal and moves to a steady position displaced from null by an amount equal to 5.93% of the maximum stroke of the actuator. No failure detection and depressurization of a channel is indicated by the test results.

Figure 23 shows the sequential application of a negative hardover input (-10 volts) to channels 1, 2 and 3. The failure transients are similar to that recorded for the positive hardover inputs shown on Figure 22. For the first hardover input into channel 1, an actuator deviation of 0.37% of the maximum actuator stroke occurs. The total duration of the failure deviation is .85 seconds. The small peak on the end of the deviation due to the hardover input into channel 1 is caused by the changing of the fourth channel force limit from a 50% to a 100% condition.

The deviation for the second failure is 0.58% of the maximum actuator position. The deviation for the third failure is 0.79% of the maximum actuator position. The 0.79% is the same deviation measured for the positive hardover input into channel three (as shown on Figure 22). Note that the third failure applied to channel 3 causes channel three to be depressurized, allowing channel four to recenter the actuator. Some channel mismatch between channels is indicated by the actuator output after the second and third failures. The actuator position after the failed channels are depressurized is different from the no failure position. For example, the null shift shown on Figure 23 after the second channel failure is approximately 0.14% of the maximum actuator stroke.

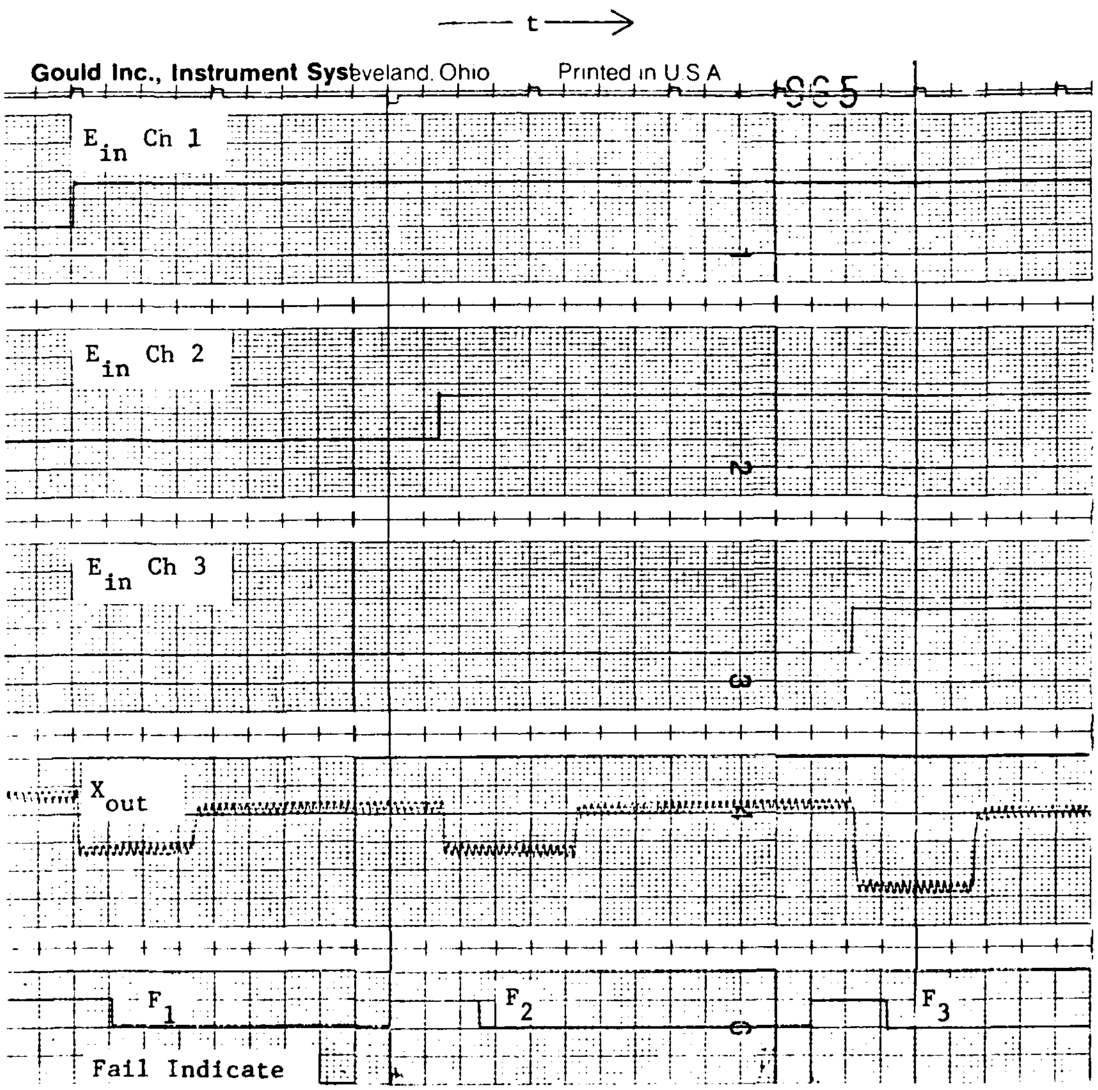
Figures 24 and 25 show the effect of hardover inputs with the actuator biased initially to 50% extend and retract positions. Figure 24 shows the effect of hardover input failures with the actuator biased to a 50% extend postion. The actuator deviations from the commanded position are quite similar to the unbiased failure deviations. The first failure produces a deviation of 0.42% of the maximum actuator stroke, the second failure produced a deviation of 0.40% of maximum actuator stroke deviation. The third failure produced a deviation of 0.79% of the maximum actuator stroke.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date
Prepared 5/10/79

TEST - Failure Transients - Condition 18




Scale: $E_{in}$ = 1.000 v/ div
$X_{out}$ = 0.0007 in/div
t = 20 div/sec

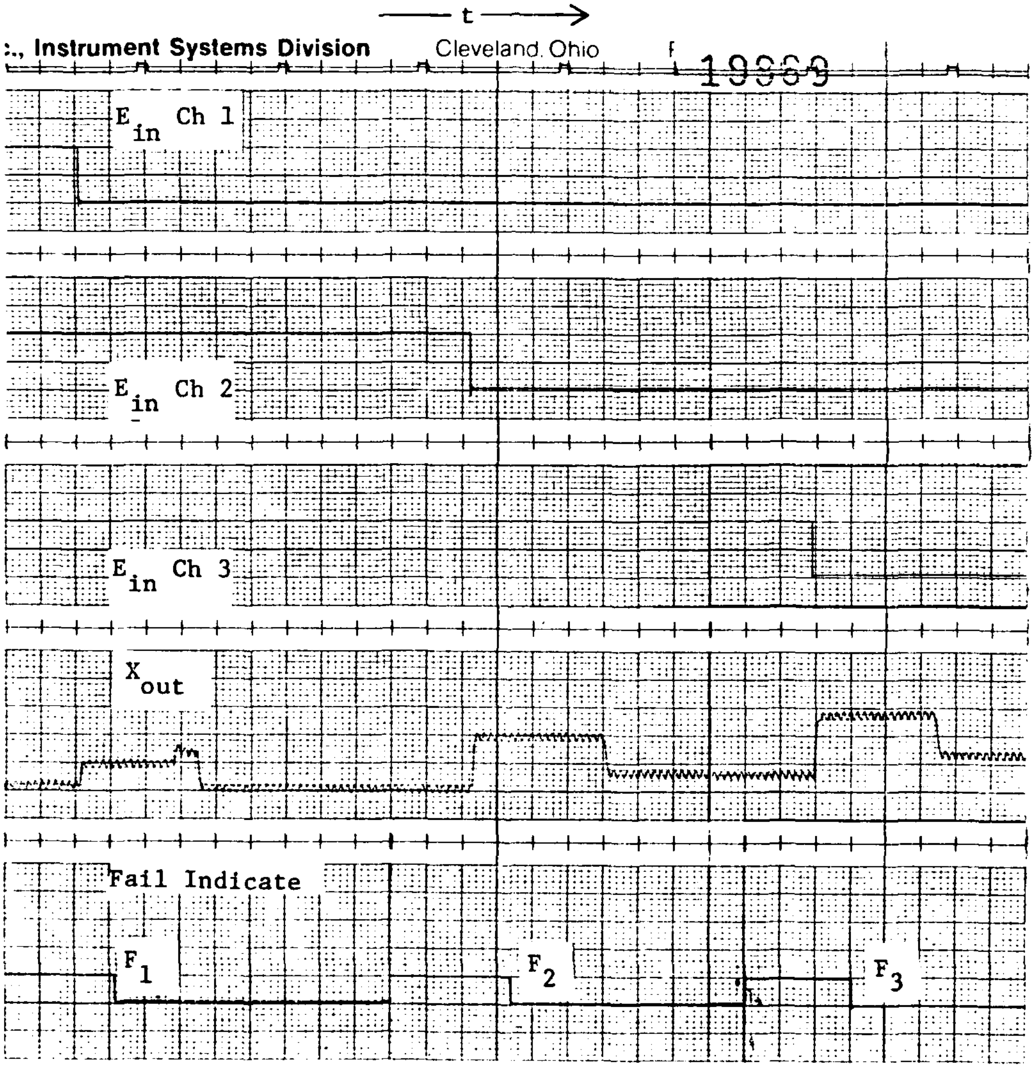
FIGURE 24 Failure Transients - Condition 18

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date
Prepared 5/10/79

TEST - Failure Transients - Condition 19




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.0013 in/div
t = 20 div/sec

FIGURE 25 Failure Transients - Condition 19

Figure 25 shows the effect of a negative hardover input with the actuator biased initially to a 50% retract position. The transients are essentially the same as measured with the actuator unbiased as an initial condition. The deviations measured for the three failures are 0.32, 0.52 and 0.73% of the maximum actuator position, corresponding to the first, second and third hardover failures. Null shifts after the second and third failures are 0.16 and 0.32% of the maximum actuator stroke, respectively.

Figure 26 shows the effect of positive hardover inputs applied sequentially to channels 1, 2 and 3 with the actuator biased initially to a 50% retract position. The actuator output transients, with a time duration of .85 seconds, are 0.32% of the maximum stroke for the first input failure to channel 1, 0.37% of the maximum stroke for the second failure to channel 2 and 0.79% of the maximum actuator stroke for the third failure applied to channel 3. This is similar to the actuator output deviations for positive hardover inputs without an initial bias applied to the actuator.

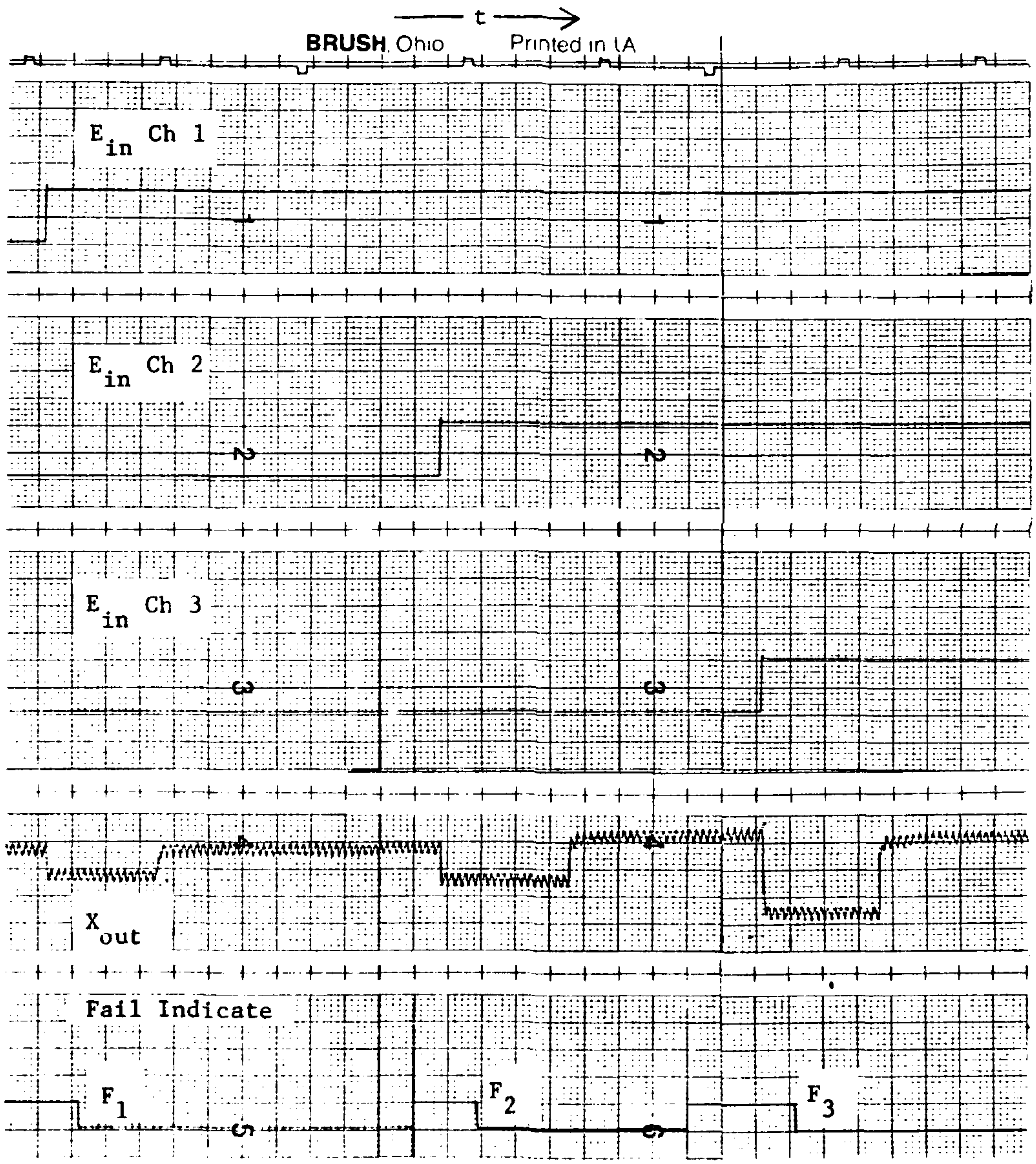
Figure 27 shows the effect of a negative hardover input applied sequentially to channels 1, 2 and 3 with the actuator biased to a 50% retract position. The actuator output deviation for the channel 1 input application is 0.47% of the maximum actuator stroke. The change in the channel 4 force limit is observable as the small transient peak just before the channel 1 is depressurized and the actuator returned towards it's initial position. The deviation of the actuator upon the second and third failures is 0.63 and 0.58% of the maximum actuator position, respectively. The deviations resemble in magnitude and duration the transients encountered for the other hardover test conditions of initial bias and input polarity (Reference Figures 22, 23, 24, 25 and 26).

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date
Prepared 5/21/79

TEST - Failure Transients - Condition 20




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.0007
t = 20 div/sec

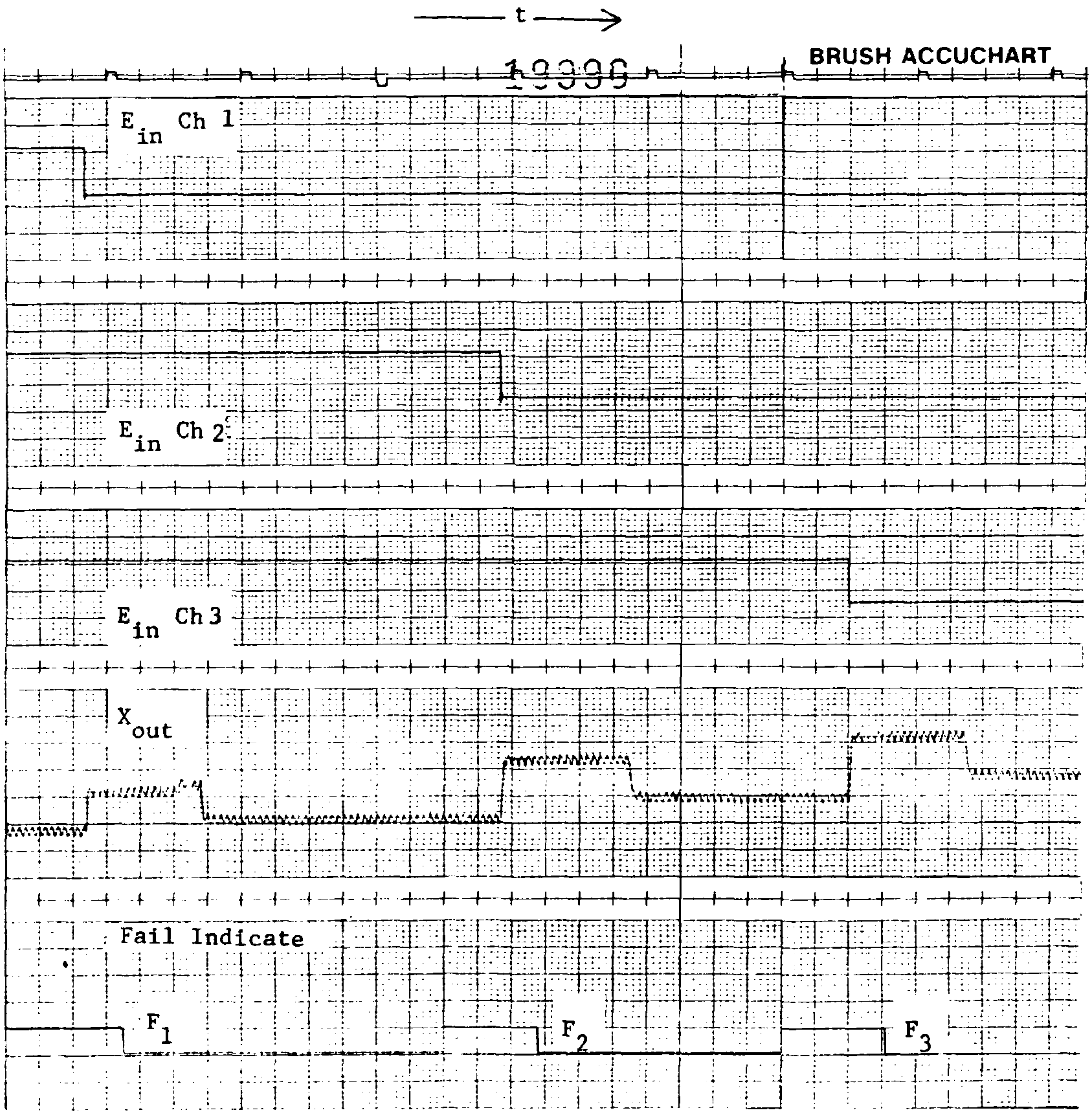
FIGURE 26 Failure Transients - Condition 20

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM – Grumman - Bertea Unit
Configuration A

Date
Prepared 5/11/79

TEST – Failure Transients - Condition 21




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.007 in/div
t = 20 div/sec

FIGURE 27 Failure Transients - Condition 21

Figure 28 and 29 show the effect of hardover input failures applied sequentially to channels 1, 2 and 3 with the actuator operating at ½ the bandpass frequency (10 Hz) at a maximum unsaturated input amplitude. Figure 28 shows the effect of positive hardover inputs. The effect of the failures is primarily one of a null shift until the third failure is applied. For the first positive hardover input into channel one, the operating position deviates 0.50% of the maximum stroke of the actuator. The amplitude of the 10 Hz actuator motion does not change. Upon depressurization of channel 1, the actuator null returns to the original null position. For a second positive hardover input, the actuator null shifts 0.74% of the maximum actuator stroke. For the third hardover input into channel three, the actuator ceases to respond to the 10 Hz input and takes a position displaced from null by 2.74% of the maximum stroke of the actuator.

Figure 29 shows the effect of a negative hardover inputs under the same operating conditions as Figure 28. The effect of the hardover inputs is again primarily a null shift until the control channel with the applied hardover input is depressurized. For the first hardover input applied to channel 1, the actuator output deviates 0.49% of the maximum stroke of the actuator. For the second hardover input into channel 2, the actuator deviates 1.24% of the maximum stroke. For the third hardover input into channel 3, the actuator shifts to a position displaced from null by 2.72% of the maximum stroke. These results are similar to the hardover input effects shown on Figure 29 with the difference that the polarity of the deviations is opposite.

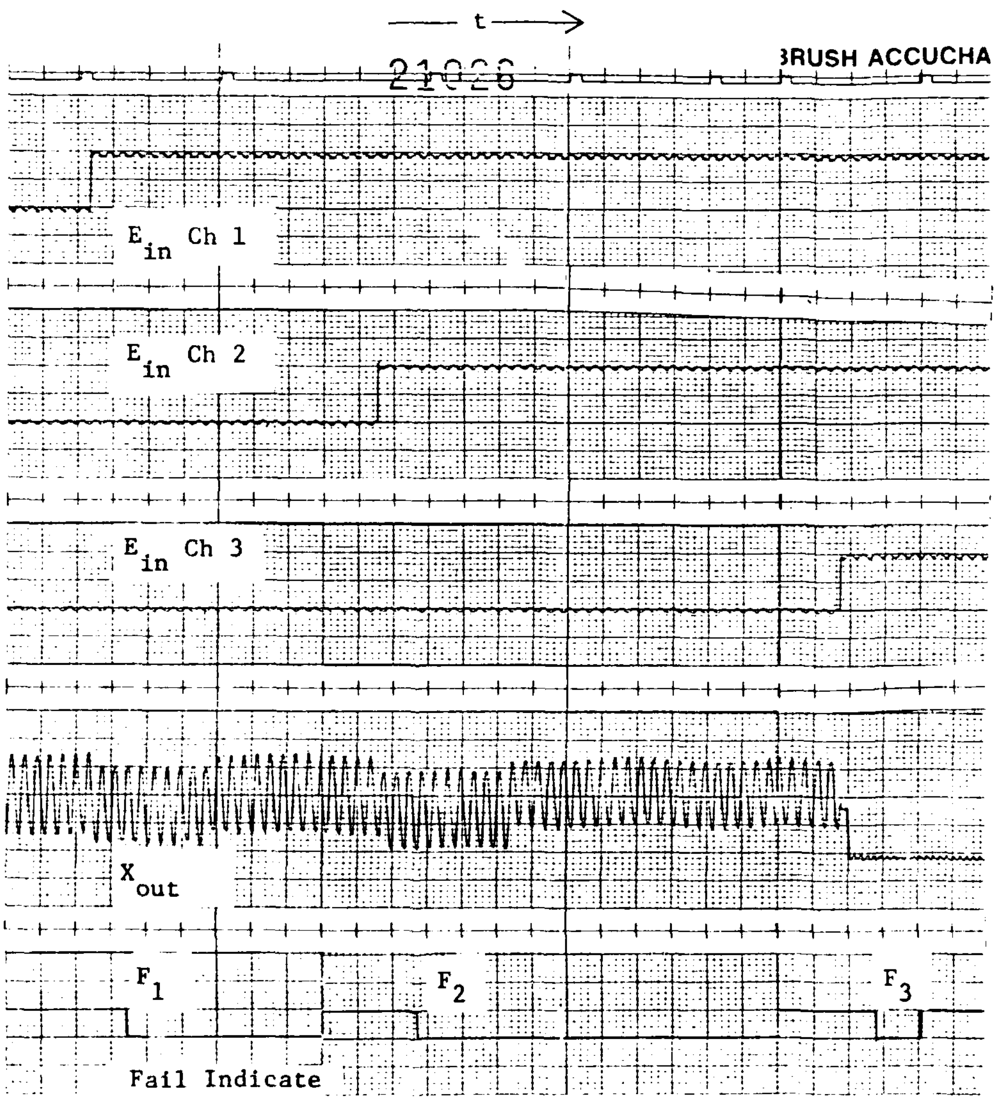
The principal difference between the hardover effects with the actuator cycling at 10 Hz as opposed to being at a static position is the effect of the third failure. For the static input conditions, the actuator final position is closer to the "no failure" null position than when the actuator is cycling at 10 Hz.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date
Prepared 5/23/79

TEST - Failure Transients - Condition 22




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.0033 in/div
t = 20 div/sec

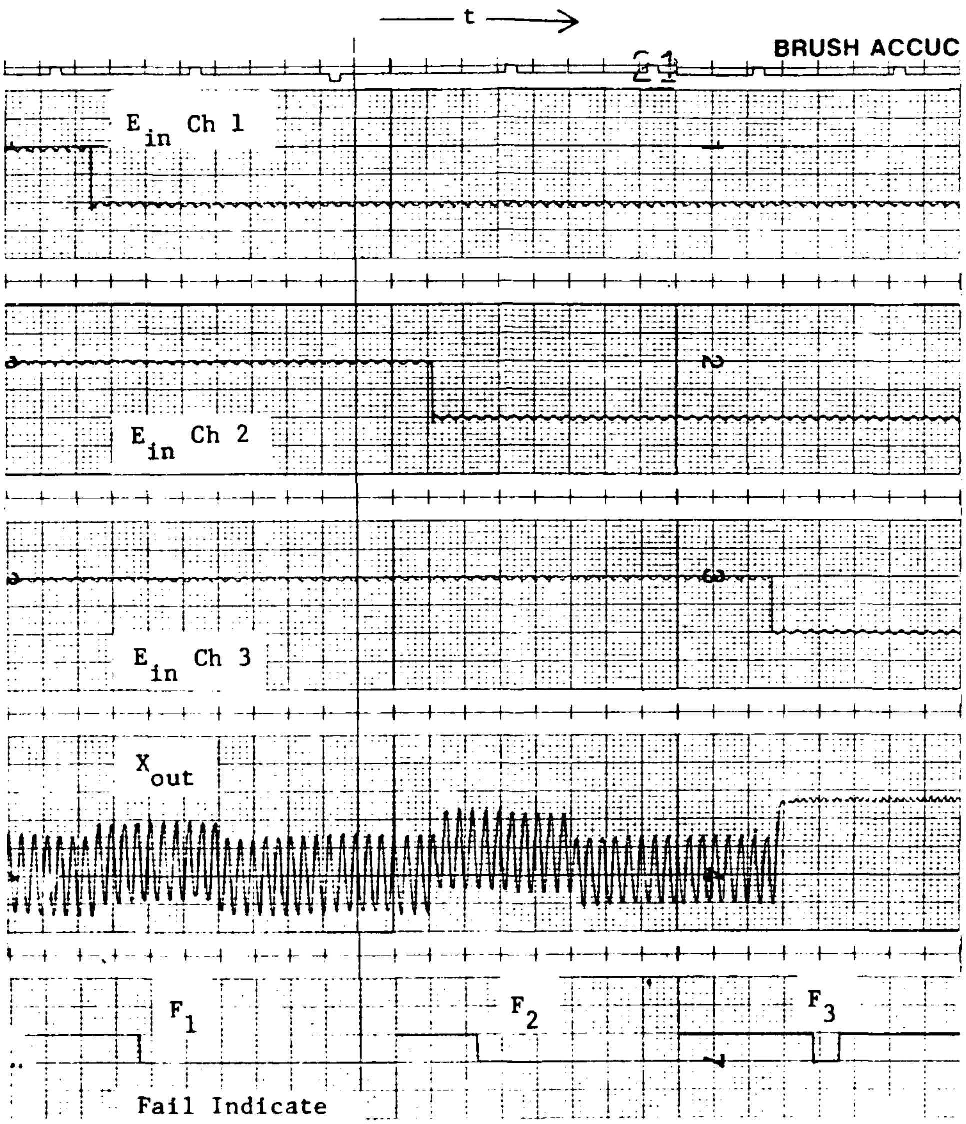
FIGURE 28 Failure Transients - Condition 22

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date
Prepared 5/23/79

TEST - Failure Transients - Condition 23




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.0033 in/div
t = 20 div/sec

FIGURE 29 Failure Transients - Condition 23

AD-A091 559 DYNAMIC CONTROLS INC DAYTON OHIO F/G 1/3
RESEARCH AND DEVELOPMENT OF CONTROL ACTUATION SYSTEMS FOR AIRCR--ETC
JUL 80 G D JENNEY F33615-77-C-3077
UNCLASSIFIED AFFDL-TR-79-3117-VOL-2 NL

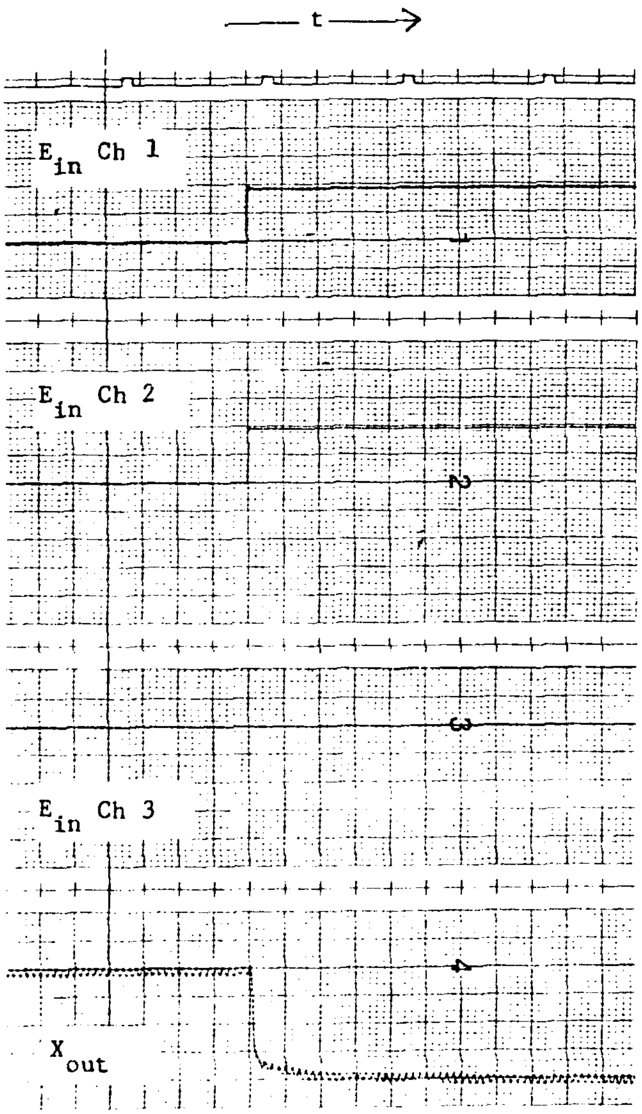
2 OF 5
AD
A091559

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date
Prepared 5/23/79

TEST - Failure Transients - Condition 24




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.0013 in/div
t = 20 div/sec

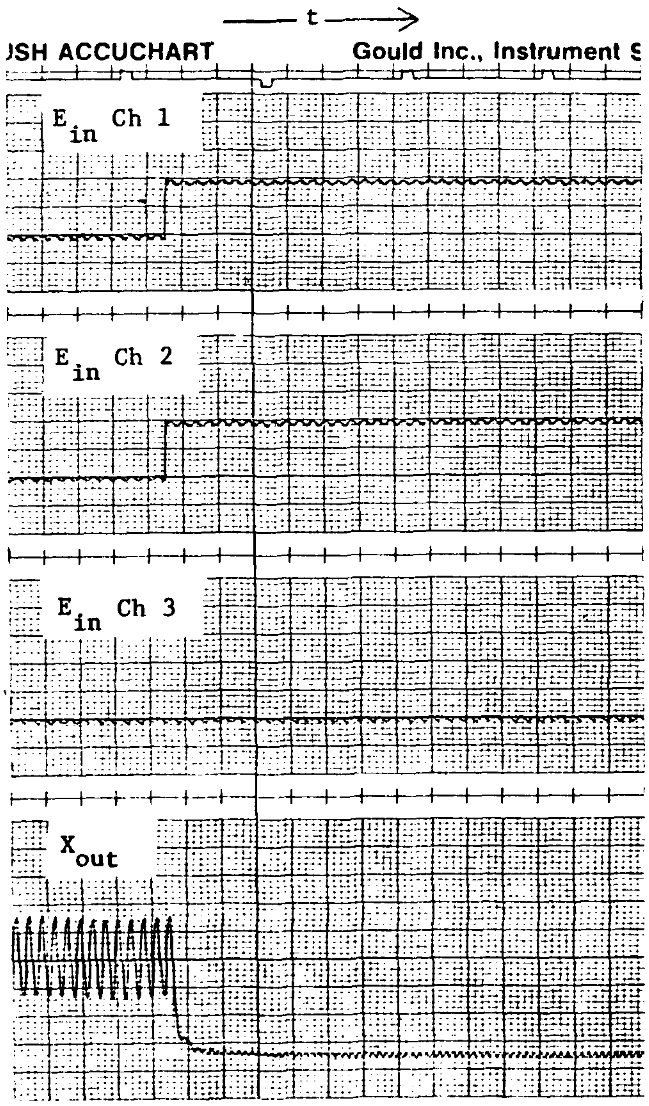
FIGURE 30 Failure Transients - Condition 24

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date Prepared 5/28/79

TEST - Failure Transients - Condition 25




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.0033 in/div
t = 20 div/sec

FIGURE 31 Failure Transients - Condition 25

### 3.5.3.4 Slowover Input Transient

Figures 32 through 37 show the failure transients associated with a slowover input failure applied sequentially to channel 1, 2 and 3 for both extend and retract slowover inputs.

Figure 32 shows the effect of an extend slowover ramp of an amplitude varying from 0 to 1.0 volts at a rate of 0.4 volts/sec applied to channel 1. The actuator initially responds to the input until the failure logic depressurizes channel 1 and changes the force limit of channel 4. The maximum actuator deviation from null is 0.58% of the maximum actuator stroke.

Figure 33 shows the effect of an extend slowover ramp of an amplitude varying from 0 to 1.0 volts at a rate of 0.4 volts/sec applied to channel 2 (after channel 1 has been depressurized and channel 4's force limit increased to 100%). The output deviation of the actuator is 0.78% of the maximum actuator stroke.

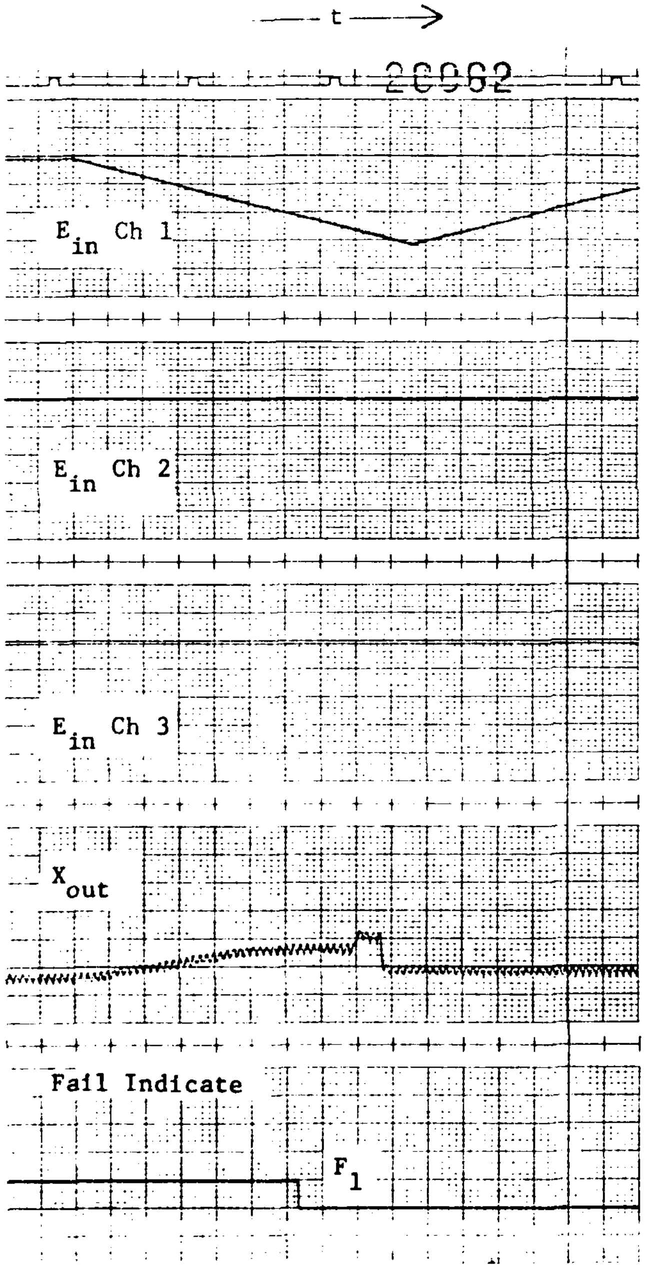
Figure 34 shows the effect of an extend slowover ramp of an amplitude varying from 0 to 1.0 volts at a rate of 0.4 volts/sec applied to channel 3 (after channel 1 and 2 have been depressurized and channel four's force limit increased to 100%). The output of the actuator deviates from null by 0.78% of the maximum actuator stroke and then returns towards null, stopping at a displacement 0.39% of the maximum actuator stroke from the original null position.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date
Prepared 5/22/79

TEST - Failure Transients - Condition 26 (1 Ch Extend)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.0013 in/div
t = 20 div/sec

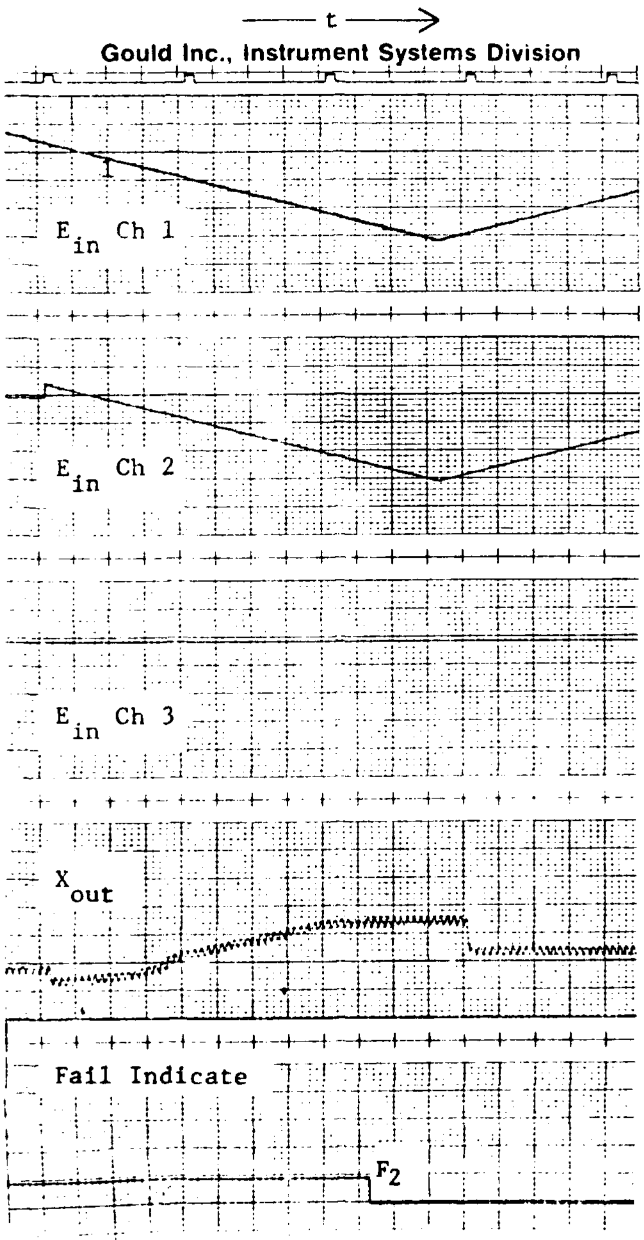
FIGURE 32 Failure Transients - Condition 26 (1 Ch Extend)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date
Prepared 5/22/79

TEST - Failure Transients - Condition 26 (2 Chs. Extend)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.0013 in/div
t = 20 div/sec

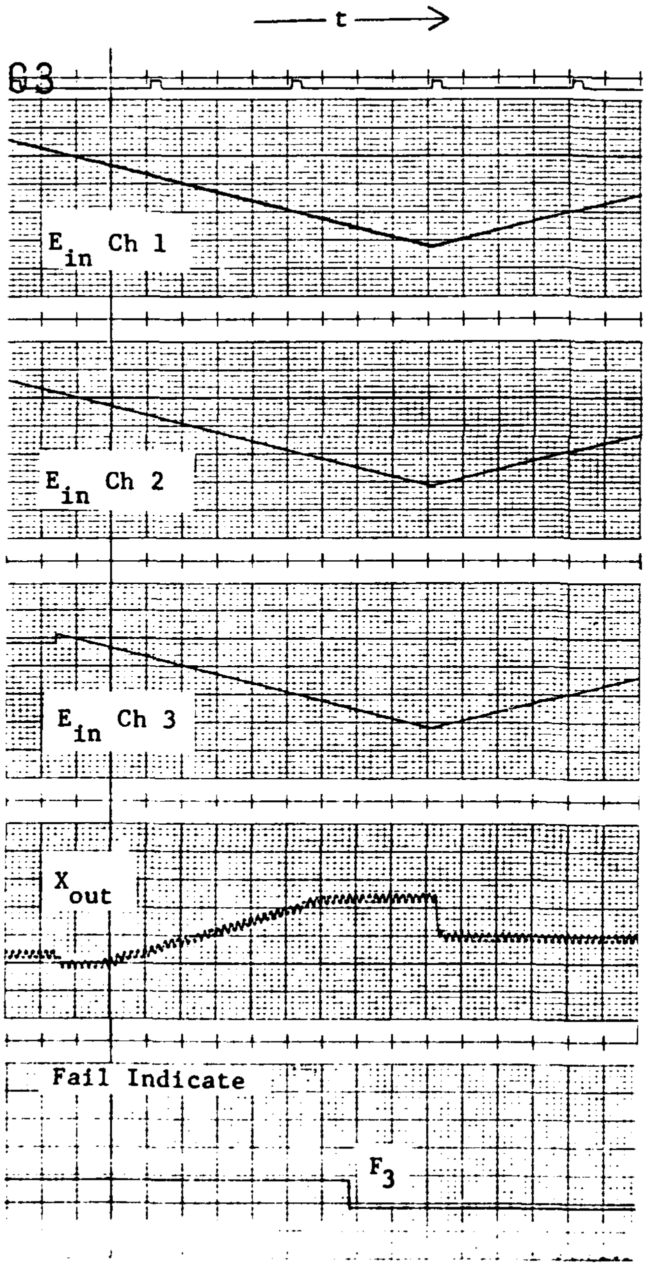
FIGURE 33 Failure Transients - Condition 26 (2 Chs. Extend)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date
Prepared 5/22/79

TEST - Failure Transients - Condition 26 (3 Chs. Extend)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.0013 in/div
t = 20 div/sec

FIGURE 34 Failure Transients - Codnition 26 (3 Chs. Extend)

The correct detection of the channel with the third failure is theoretically not possible with a voting system, since the logic doesn't have enough information for a correct vote. If the ramp had been applied to channel 4 as a third failure and channel 3 depressurized, the actuator output would have been driven hardover by the ramp input.

Figure 35 shows the effect of the application of a retract ramp input to channel 1 with the other channel inputs grounded. The actuator output deviates from null by 0.49% of the maximum actuator stroke and then returns to null upon depressurization of channel 1 and the changing of the force limit on channel 4.

Figure 36 shows the effect of the application of a retract ramp input to channel 2 with channel 1 depressurized and channel 4 changed to a 100% force capability. The actuator output deviates from null by 0.49% of the maximum actuator stroke and then returns to null upon depressurization of channel 2.

Figure 37 shows the effect of the application of the .4 volt/sec retract ramp input to channel 3 with channel 1 and 2 depressurized and channel 4 with a 100% force capability. The output of the actuator deviates 0.88% of the maximum actuator stroke and then returns to null after channel 3 is depressurized.

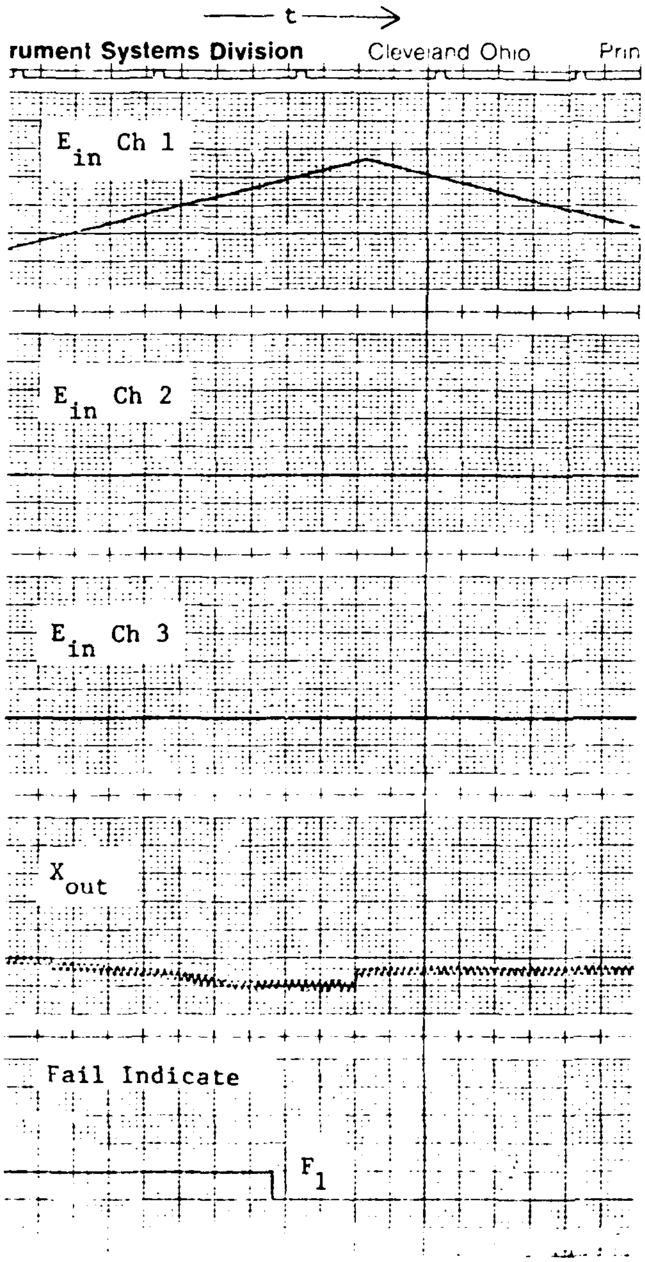
Figure 38 shows the effect of sequentially applying ramp inputs to channel 1, 2 and 3 while operating the system at 10 Hz at a maximum unsaturated amplitude. The effect of the first two ramp inputs is to cause a null shift of the actuator output with no observable change in the amplitude of the 10 Hz motion. The null shift for the channel 1 input ramp application is 0.49% of the actuator maximum stroke. The null shift for the channel 2 input ramp application is 0.74% of the actuator stroke. The third ramp input creates a null shift of 1.50% of the maximum actuator stroke. After the third failure the actuator continues to respond to the 10 Hz input into channel 4.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date
Prepared 5/22/79

TEST - Failure Transients - Condition 26 (1 Ch Retract)




Scale: $E_{in}$ = 0.050 mv/div
$X_{out}$ = 0.0013 in/div
t = 20 div/sec

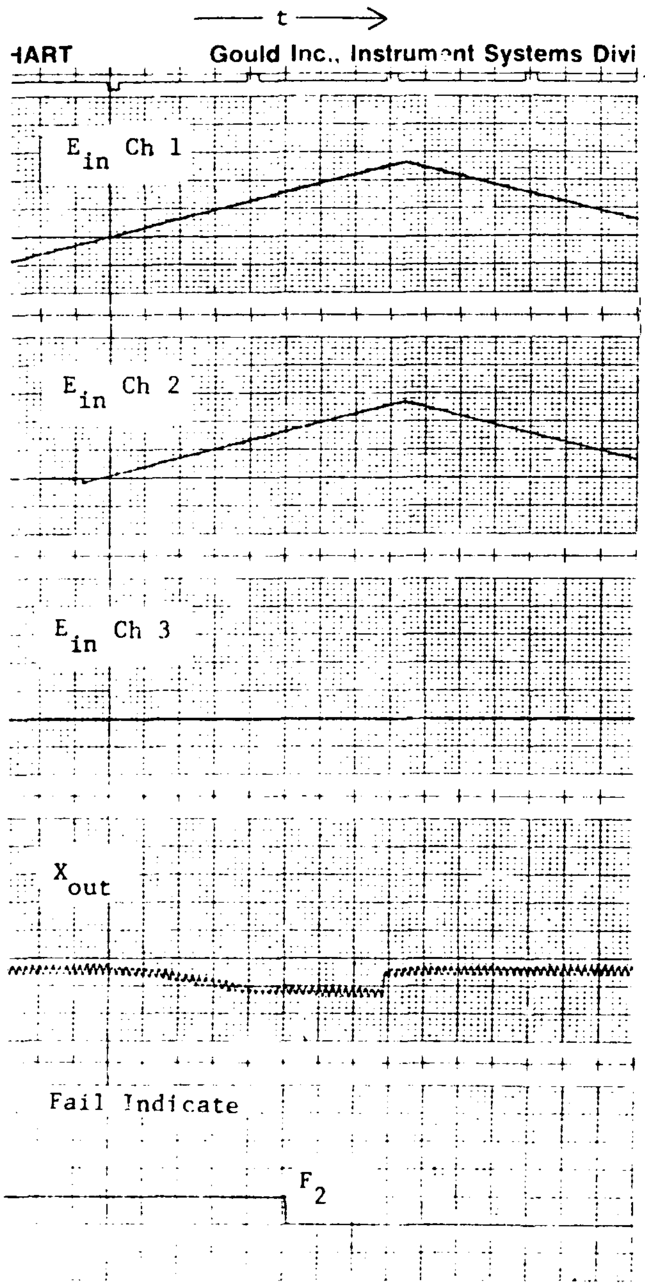
FIGURE 35 Failure Transients - Condition 26 (1 Ch Retract)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date
Prepared 5/22/79

TEST - Failure Transients - Condition 26 (2 Chs. Retract)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.0013 in/div
t = 20 div/sec

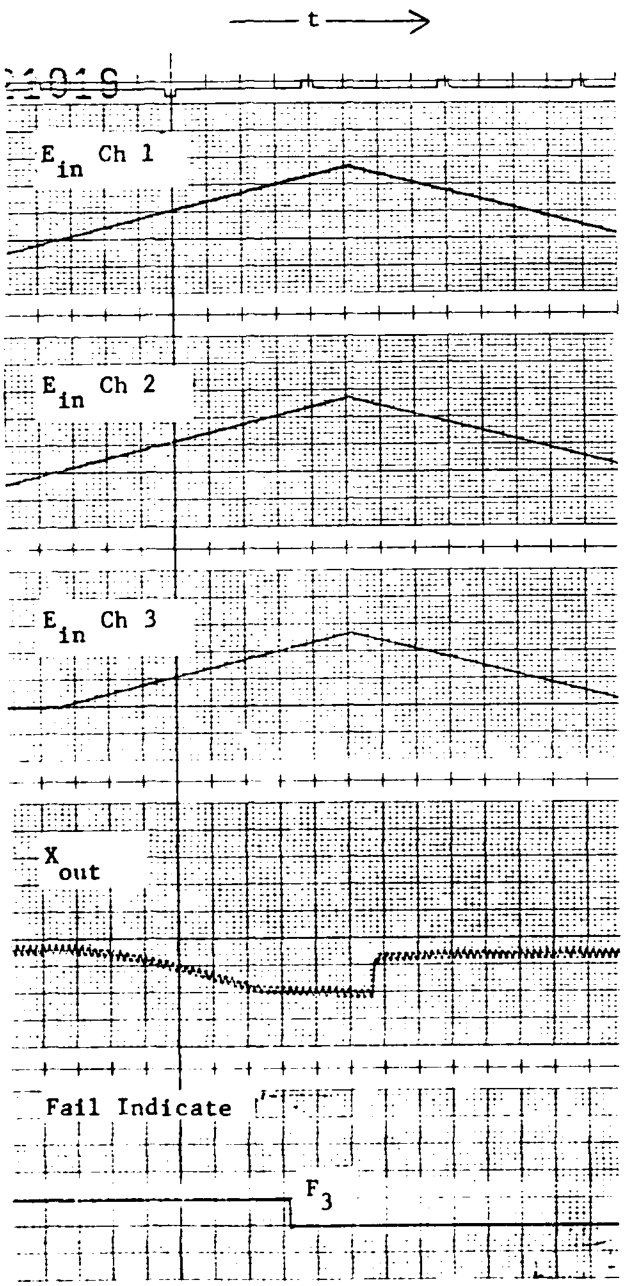
FIGURE 36 Failure Transients - Condition 26 (2 Chs. Retract)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date
Prepared 5/22/79

TEST - Failure Transients - Condition 26 (3 Chs. Retract)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.0013 in/div
t = 20 div/sec

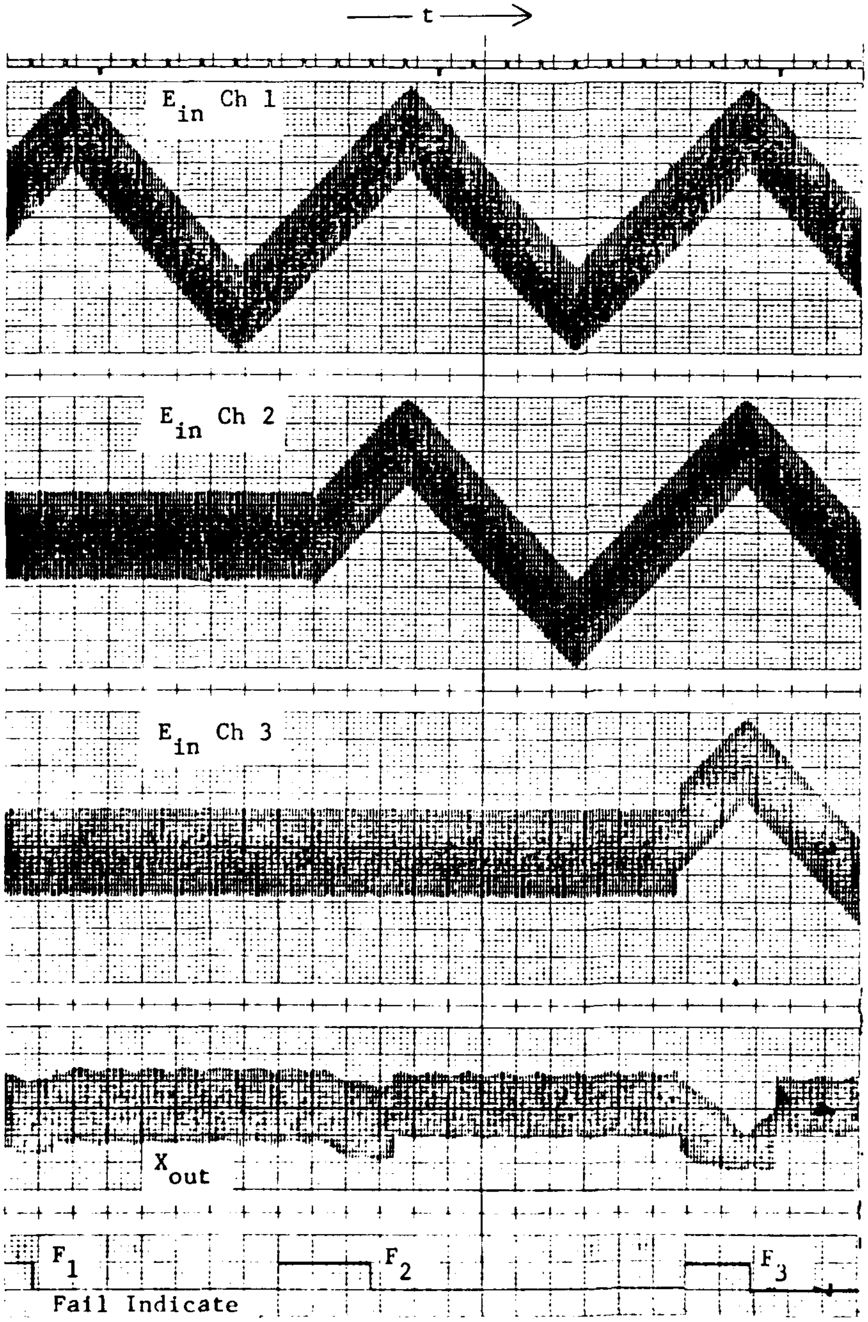
**FIGURE 37 Failure Transients - Condition 26 (3 Chs. Retract)**

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date
Prepared 5/24/79

TEST - Failure Transients - Condition 27




Scale:
$E_{in}$ = 0.050 v/div
$X_{out}$ = 0.0033 in/sec
t = 5 div/sec

FIGURE 38 Failure Transients - Condition 27

### 3.5.4 Failure Logic Detection Characteristics

#### 3.5.4.1 General

This section presents limited test data on the failure detection circuit characteristics as used during the configuration A testing. Since the amplitude and duration of the transients resulting from a control channel failure in the configuration evaluated are affected by the characteristics of the failure detection system, it is worthwhile documenting these characteristics. The test results present both the static detection level of each channel and the highest frequency at which an input amplitude 110% of the static detection level for a channel will be detected and cause the channel to be depressurized. The detection level characteristics are adjustable in terms of detection amplitude and response characteristics. The failure detection levels used are detected when channel mismatches correspond to servovalve currents 50% or greater of saturation. The time delay settings were not changed from the settings initially provided with the unit.

#### 3.5.4.2 Specific

Figure 39 shows data taken in order to establish the failure detection level for channel 1 static or "slowover" failures. A ramp input is applied to the channel 1 input while channel 2, 3 and 4 inputs are grounded. The input voltage for activating the failure indicate output is defined as the failure detection level.

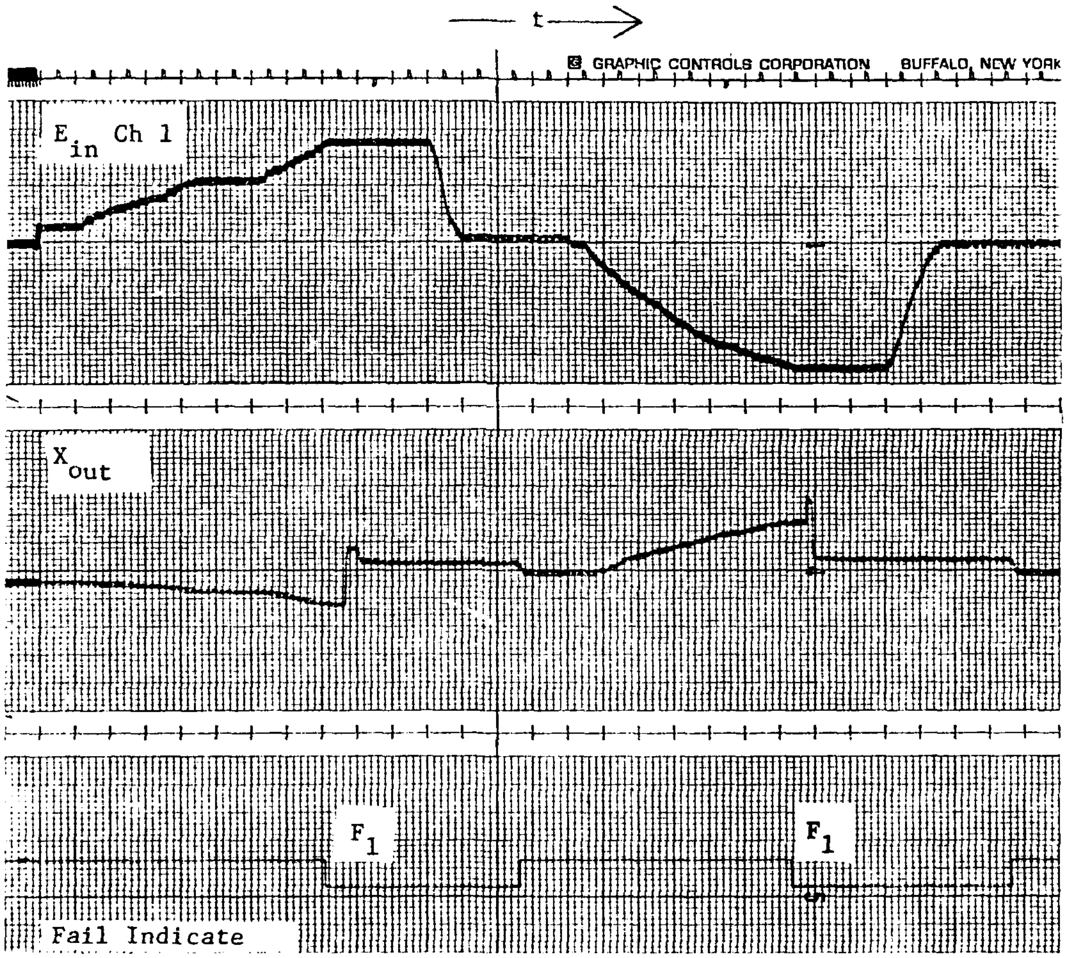
Table 8 lists the extend and retract direction failure detection input voltages for each channel of Configuration A. The input voltage for failure detection is that voltage applied to the input of a particular channel in order to cause the failure logic to vote a channel failure. Note that the magnitude of the input failure voltage for channels 1, 2 and 3 is nominally .4 ± .05 volts while the failure input for channel 4 is .2 ± .06 volts.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date Prepared 6/28/79

TEST - Failure Detection Level - Static - Ch 1




Scale: $E_{in}$ = 0.020 v/div
$X_{out}$ = 0.0007 in/div
t = 5 div/sec

FIGURE 39 Failure Detection Level - Static - Ch 1

TABLE 8

Failure Detection Level - Static

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 6/29/79

TEST ITEM - Grumman - Bertea Unit
Configuration A

TEST - Failure Detection Level - Static

| Test Condition | Channel | Fail Voltage | |
|---|---|---|---|
| | | Extend | Retract |
| 1 | 1 | -0.450 | +0.340 |
| 1 | 2 | -0.440 | +0.370 |
| 1 | 3 | -0.350 | +0.380 |
| 1 | 4 | -0.140 | +0.260 |

Figure 40 shows the data obtained in measuring the channel 1 dynamic detection level characteristics. The input to channel 1 is maintained at an amplitude of 110% of the input required to cause the failure detection level with a slowover input and the frequency of the input signal varied. As shown on Figure 40, the frequency of the input signal is reduced until the fail indicate signal shows that the channel is voted as failed and depressurized. Note that for frequencies between .4 and .3 Hz, the fail indicate signal does not latch, and the actuator continues to respond to the channel 1 input.

Table 9 shows the results of the failure logic evaluation for all four channels, measured individually with all channels operational. The general channel detection level is an input of approximately .90% of a full scale input voltage. Note the different detection frequency for channel 4. This is due to 50% force limit for that channel in the mode in which the actuator was evaluated. The detection frequency of channel 4 would decrease to that of the other channels with the increase in the force limit for that channel.

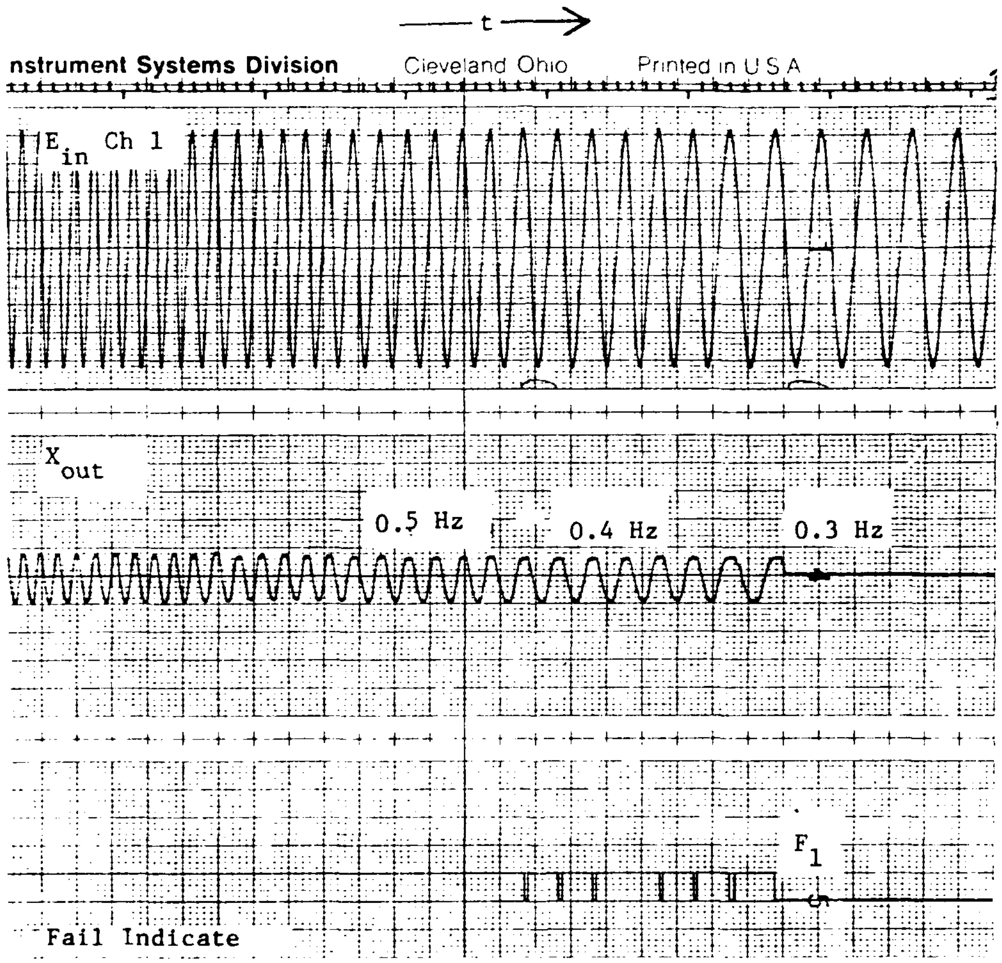
As indicated in Table 9, the failure detection circuit becomes ineffective above .8 Hz for channel 4 and above approximately .3 Hz for channels 1, 2 and 3. The difference between the channel 4 detection and the other channels is probably due to the reduced force limit used with channel 4 during the particular test condition. The test results indicate that the failure logic dynamic characteristics degrade frequencies at greater than one-twentieth of the control system bandpass of 20 Hz. This indicates that oscillatory failures would not be detected over a large portion of the control actuator system frequency response.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date
Prepared 6/28/79

TEST - Failure Detection Level - Dynamic - Ch 1




Scale: $E_{in}$ = 0.020 v/div
$X_{out}$ = 0.0013 in/div
t = 2 div/sec

FIGURE 40 Failure Detection Level - Dynamic - Ch 1

TABLE 9

Failure Detection Level - Dynamic

DYNAMIC CONTROLS, INC.

Test Data

Date Prepared 6/29/79

TEST ITEM - Grumman - Bertea Unit
Configuration A

TEST - Failure Detection Level - Dynamic

| Test Condition | Channel | Fail Hz |
|---|---|---|
| 1 | 1 | 0.3 |
| 1 | 2 | 0.4 |
| 1 | 3 | 0.3 |
| 1 | 4 | 0.8 |

## 3.6 Specific Test Procedure - Configuration B

### 3.6.1 General

Configuration B of the force sharing system was identical to Configuration A with the exception that the equalizer feedback network was connected (Reference Figure 5). The equalizer network was used for failure detection only for the Configuration A tests. For the Configuration B testing, the connection of the pressure feedback signal was supposed to reduce the failure sensitivity of the system to input signal mismatch. The equalizer pressure feedback loop was used to reduce the pressure gain of the control valve for differential pressures across the actuator of 1000 psi or greater. Figure 41 shows the theoretical characteristic of the force output of a stalled actuator as a function of the input signal.

As received from Grumman Corporation, the equalizer feedback gain was set to allow approximately a 4.3% input change of full scale input for a stalled actuator before a failure was voted. Because of the commonalty of gain elements for both the pressure feedback and position loops of the channel control electronics, the input mismatch tolerance was reduced to 2.2% of full scale input (for a failure vote) when the position loop response was changed to a break frequency of 20 Hz. This reduction of allowable channel mismatch from the original value was not considered significant enough to invalidate the evaluation of the equalizer technique in terms of its intended function. Note that the 2.2% of full scale corresponds to an input voltage of .44 volts for the test system (since the input voltage is $\pm 10$ volts for a total of 20 volts full scale).

### 3.6.2 Specific

The test procedure used for evaluating the Configuration B performance is similar to that used for Configuration A. Table 9 lists the 32 test conditions and the values used for evaluating Configuration B. There are 5 more test conditions applied to the Configuration B evaluation than for the Configuration A evaluation. These additional test conditions include hydraulic failures for transient measurements and several simultaneous failure conditions. However, the 27 test conditions used for Configuration A were also used for Configuration B in order to provide a direct comparison of the performance of the two configurations.

Test conditions 1 through 11 are the various operational modes of the system. The performance measurements described in Section 2.2.1 were used to document the performance characteristics for these test condition. All other test conditions correspond to the "Failure Effect on Performance" measurements described in Section 2.2.2 and the "Input Deviations Effect" measurements described in Section 2.2.3.

Test conditions 12 through 32 correspond to "Failure Removal Transients" measurements described in Section 2.2.4. The test conditions 12 through 32 describe both the initial conditions and the test used for creating the transient.

## 3.7 Test Results

### 3.7.1 General

The data presentation format for the test results of Configuration B evaluation is the same as for the Configuration A evaluation. For all measurements except the transient measurements, the test data is presented in tabular form . For the transient data, the results are presented as recorded.

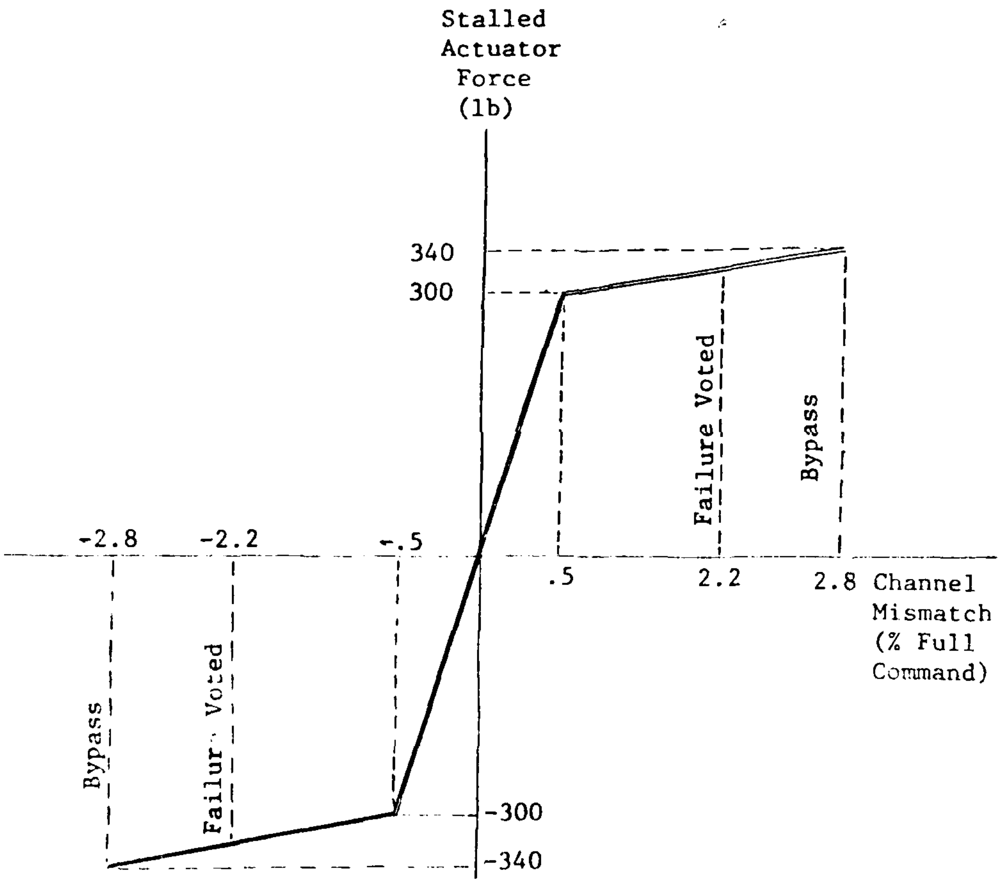



FIGURE 41 Equalizer Effect on Voted Force Output

TABLE 10

TEST CONDITIONS

Grumman - Bertea Unit - Configuration B

| Test Condition | Test Condition Description |
|---|---|
| 1 | Baseline - all channels nulled, pressurized (3000 psi) and operating correctly. |
| 2 | One channel (1) electrical failure. |
| 3 | Two channels (1 & 2) electrical failure. |
| 4 | One channel (1) hydraulic failure. |
| 5 | Two channels (1 & 2) hydraulic failure. |
| 6 | One channel (1) with negative input offset (biased to 90% of trip level). |
| 7 | One channel (1) with positive input offset (biased to 90% of trip level). |
| 8 | Two channels (1 & 2) with negative input offsets (both channels biased negatively to 90% trip level). |
| 9 | Two channels (1 & 2) with opposing input offsets (channel 1 biased positively and channel 2 biased negatively to 90% trip level). |
| 10 | One channel (1) with hydraulic pressure reduced to 2000 psi. |
| 11 | Two channels (1 & 2) with hydraulic pressure reduced to 2000 psi. |
| | FAILURE TRANSIENTS |
| 12 | Ground inputs to channels 1, 2 & 3 sequentially with system at 50% extend. |
| 13 | Ground inputs to channels 1, 2 & 3 sequentially with system at 50% retract. |
| 14 | Ground inputs to channels 1, 2 & 3 sequentially with the system operating at ½ the bandpass frequency (10 Hz) with the maximum unsaturated input. |

TABLE 10

TEST CONDITIONS (cont'd)

| Test Condition | Test Condition Description |
|---|---|
| 15 | Ground inputs to channels 1, 2 & 3 sequentially with the system operating at 0.5 Hz with the maximum unsaturated input. |
| 16 | Positive hardover (+10V) sequentially applied to channels 1, 2 & 3 with the system at null. |
| 17 | Negative hardover (-10V) sequentially applied to channels 1, 2 & 3 with the system at null. |
| 18 | Positive hardover (+10V) sequentially applied to channels 1, 2 & 3 with the system biased to 50% extend. |
| 19 | Negative hardover (-10V) sequentially applied to channels 1, 2 & 3 with the system biased to 50% extend. |
| 20 | Positive hardover (+10V) sequentially applied to channels 1, 2 & 3 with system biased to 50% retract. |
| 21 | Negative hardover (-10V) sequentially applied to channels 1, 2 & 3 with system biased to 50% retract. |
| 22 | Positive hardover (+10V) sequentially applied to channels 1, 2 & 3 with system operating at ½ the bandpass frequency (10 Hz) with the maximum unsaturated input amplitude. |
| 23 | Negative hardover (-10V) sequentially applied to channels 1, 2 & 3 with system operating at ½ the bandpass frequency (10 Hz) with the maximum unsaturated input amplitude. |
| 24 | Negative hardover (-10V) applied simultaneously to channels 1 & 2 with the system biased to 50% extend. |
| 25 | Ground the inputs to channels 1 & 2 simultaneously with the system operating at 0.5 Hz with the maximum unsaturated input amplitude. |

TABLE 10

TEST CONDITIONS (cont'd)

| Test Condition | Test Condition Description |
|---|---|
| 26 | Positive hardover (+10V) or negative hardover (-10V) applied simultaneously to channels 1 & 2 with the system at null. |
| 27 | Positive hardover (+10V) or negative hardover (-10V) applied simultaneously to channels 1 & 2 with the system operating at ½ the bandpass frequency (10 Hz) with the maximum unsaturated input amplitude. |
| 28 | Apply a ramp of zero to 1.0 volt at 0.4 volts/sec ($\pm$1V at 0.1 Hz) to channels 1, 2 and 3 sequentially with system at null. |
| 29 | Apply a ramp of 0 to 1.0 volt at 0.4 volts/sec ($\pm$1.0V at 0.1 Hz) sequentially to channels 1, 2 and 3 with system operating at ½ the bandpass frequeny (10 Hz) with the maximum unsaturated input amplitude. |
| 30 | Channel 1 only failed hydraulically. |
| 31 | Channels 3 & 4 failed hydraulically, channels 1 & 2 failed hydraulically. |
| 32 | All channels failed hydraulically. |

The data presentation format for the test results of Configuration B evaluation is the same as for the Configuration A evaluation. For all measurements except the transient measurements, the test data is presented in tabular form. For the transient data, the results are presented as recorded. The following results are presented in tabulated form for conditions 1 through 11:

1. Static Threshold
2. Dynamic Threshold
3. Frequency Response
4. Distortion
5. Hysteresis
6. Saturation Velocity

For these test results reduced to tabular form, a sample of the recorded data is included with the table. The linearity and step responses for conditions 1 through 11 are presented in recorded data format.

As was done for Configuration A, the measurements of threshold and hysteresis for Configuration B are represented in terms of the percent of the input required for full actuator stroke and the input required for full servovalve output flow. This method of presenting hysteresis and threshold describes the results in terms which allow comparing different control valve driving mechanizations independent of the actuator stroke used for the mechanization.

The test results are presented for Configuration B as follows:

1. Performance measurements for Conditions 1 through 11
2. Failure transients for Conditions 1 through 11
3. Failure logic detection characteristics

### 3.7.2 Performance Measurements

#### 3.7.2.1 Static Threshold

Figure 42 shows the data recorded in establishing the static threshold for Configuration B and test Condition 1. As shown on this figure, the amplitude of the ramp input is increasing with increasing time. The threshold value is determined by the amplitude of the input where the actuator output starts to respond to the ramp input. The noise content of the output is due to the background noise picked up by the instrumentation lines to the recorder and is the result of the input levels measured during the particular test. The edge of the noise band shows the actuator responding to the .1 Hz input ramp. Table 11 lists the static threshold values measured for test conditions 1 through 11.

The threshold measured for the test conditions for Configuration B is approximately the same or slightly greater than those measured for Configuration A. Test Conditions 6,7,8 and 9 were expected to show effects of the pressure equalization feedback (since the input bias levels would result in differential pressure levels across the control system actuators greater than 1000 PSI, actuating the pressure feedback and reducing the press re gain of the servovalves.) The threshold for Conditions 6, 7 and 8 are larger than that measured for Configuration A. However, the threshold for Test Conditions 1, 2, 3 and 5 also show larger values than for Configuration A. These test conditions were not expected to create threshold values greater than that measured for Configuration A. As commented on for Configuration A, this value is considerably greater than a normal servovalve and reflects the low pressure gain for the servovalves used along with the force fight between channels.

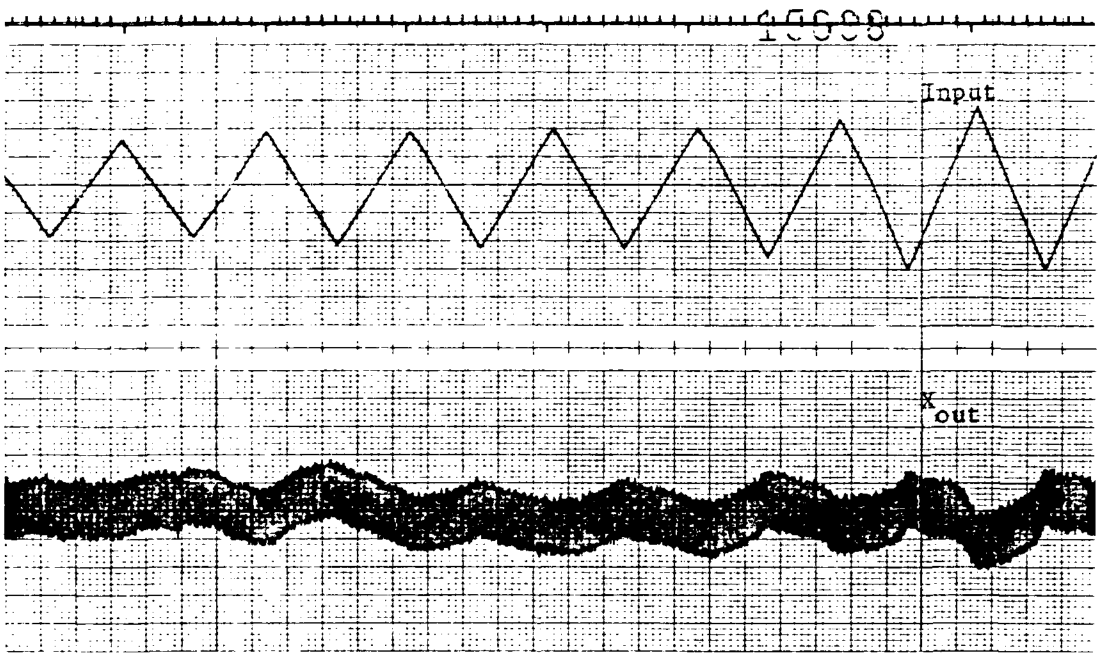
DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 4/24/79

TEST - Static Threshold - Condition 1

—— t ——>




0.1 Hz Ramp Input

Scale: Input = 0.0002 v/div

$X_{out}$ = 0.00003 in/div

t = 2 div/sec

FIGURE 42 Static Threshold - Condition 1

TABLE 11

STATIC THRESHOLD

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 4/18/79

TEST ITEM - Grumman - Bertea Unit
Configuration B

TEST - STATIC THRESHOLD

| Test Condition | Input Volts | Static Threshold: % of Max Input | Static Threshold: % of $E_v$ Max |
|---|---|---|---|
| 1 | 0.040 | 0.20 | 26.00 |
| 2 | 0.036 | 0.18 | 23.40 |
| 3 | 0.042 | 0.21 | 27.30 |
| 4 | 0.030 | 0.15 | 19.50 |
| 5 | 0.044 | 0.22 | 28.60 |
| 6 | 0.044 | 0.22 | 28.60 |
| 7 | 0.042 | 0.21 | 27.30 |
| 8 | 0.036 | 0.18 | 23.40 |
| 9 | 0.036 | 0.18 | 23.40 |
| 10 | 0.030 | 0.15 | 19.50 |
| 11 | 0.026 | 0.13 | 16.90 |

### 3.7.2.2 Dynamic Threshold

Figure 43 shows the data recorded in establishing the dynamic threshold for Condition 1. A 10 Hz sine wave input was used to drive the actuator. This frequency was .5 of the bandpass frequency at which a - 3 Db amplitude ratio occurs and was slightly lower than the 14 Hz frequency used for the Configuration A dynamic threshold evaluation. As with the static threshold measurement, the input amplitude was increased gradually with increasing time. The bottom trace of Figure 43 shows the actuator response to the input signal. Note the 100 Hz low amplitude noise signal appearing on the actuator output signal. This is instrumentation line noise pickup and not actuator motion.

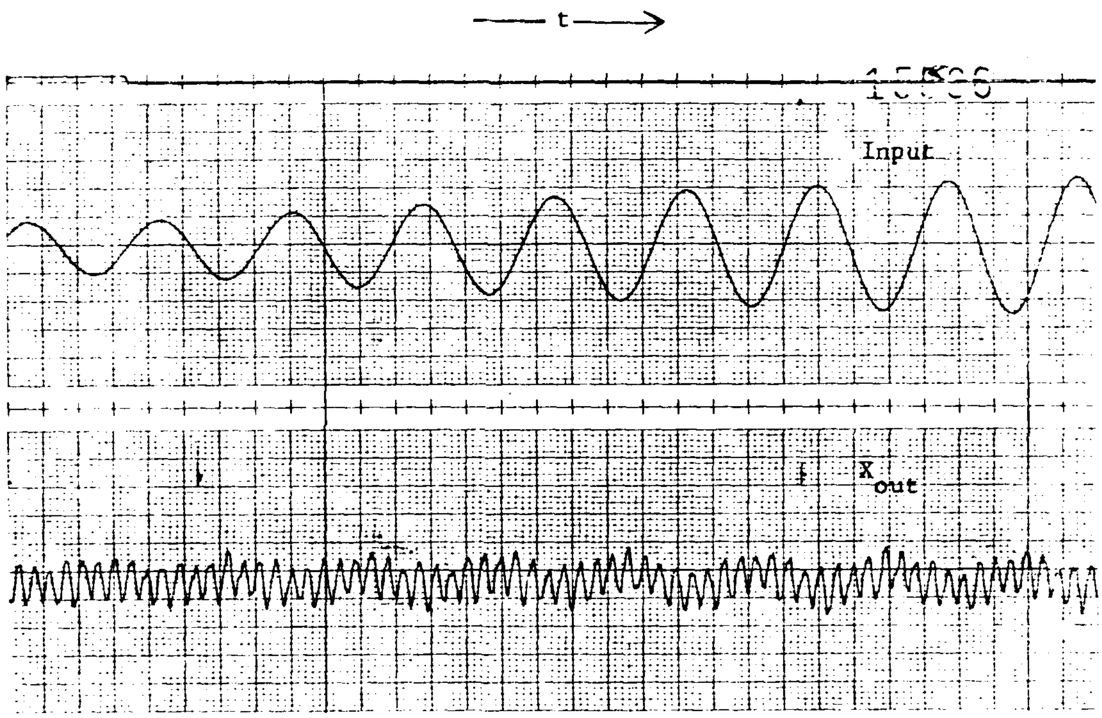
Table 12 lists the dynamic threshold measurements for Configuration B and test Conditions 1 through 11. The dynamic threshold is approximately the same as the static threshold and is lower than that measured for Configuration A. The threshold measurements show little change with the change of test conditions. This is somewhat unexpected, since the input bias conditions of test Conditions 6, 7 and 8 (for example) would be expected to cause the control channels to operate in a condition where the pressure equalization was effective and correspondingly the pressure gain of the servovalve lower than without the pressure equalization. Lower pressure gain should result in higher threshold value measurements. However, the dynamic threshold measurements for all conditions for the Configuration B testing (other than Condition 1) were lower than those of Configuration A by up to a factor of 3. The Condition 1 measurements for both configurations were essentially the same.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date Prepared 4/24/79

TEST - Dynamic Threshold - Condition 1




10.0 Hz Sine Wave Input

Scale: Input = 0.002 v/div

$X_{out}$ = 0.00003 in/div

t = 200 div/sec

FIGURE 43 Dynamic Threshold - Condition 1

TABLE 12

Dynamic Threshold

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 4/18/79

TEST ITEM - Grumman - Bertea Unit
Configuration B

TEST - DYNAMIC THRESHOLD

| Test Condition | Input Volts | Dynamic Threshold % of Max Input | % of $E_v$ Max |
|---|---|---|---|
| 1 | 0.038 | 0.19 | 24.70 |
| 2 | 0.036 | 0.18 | 23.40 |
| 3 | 0.044 | 0.22 | 28.61 |
| 4 | 0.040 | 0.20 | 26.00 |
| 5 | 0.042 | 0.21 | 27.30 |
| 6 | 0.040 | 0.20 | 26.00 |
| 7 | 0.046 | 0.23 | 29.90 |
| 8 | 0.040 | 0.20 | 26.0 |
| 9 | 0.042 | 0.21 | 27.3 |
| 10 | 0.036 | 0.18 | 23.4 |
| 11 | 0.034 | 0.17 | 22.1 |

### 3.7.2.3 Frequency Response

Figure 44 shows the frequency response recorded for the Condition 1 response measurements. The response for all test conditions resembled the response shown on Figure 44 in terms of the lack of peaking and the roll-off slope. Zero Db on Figure 44 corresponds to an input amplitude of 4% of the input for maximum actuator output stroke and was the maximum input which would not create observable output waveform distortion over the frequency range used for the measurement.

Table 13 lists the frequency response for Conditions 1 through 11 in terms of the frequencies at which the $-90^{\circ}$ phase angle and the - 3 Db amplitude ratio point occurred for each test condition. As shown on Table 13, the - 3 Db frequencies did not vary significantly from the - 3 Db frequency for Condition 1. The frequency for - 3 Db was 21 Hz for normal operation (Condition 1) and was reduced (at most) to 18 Hz for one hydraulic supply pressure set at 2000 PSI with the other at 3000 PSI (Condition 11). The frequency at which the phase angle of $-90^{\circ}$ occurred also did not vary significantly for the test conditions 1 through 11, remaining between 35 Hz (Condition 1) and 31 Hz (Conditions 3, 5, 7 and 8).

The frequency response agreed well with that for Configuration A. This indicates that even with offset conditions occurring with some of the test conditions, the net frequency response of the mechanization is not degraded by the use of the pressure equalization network.

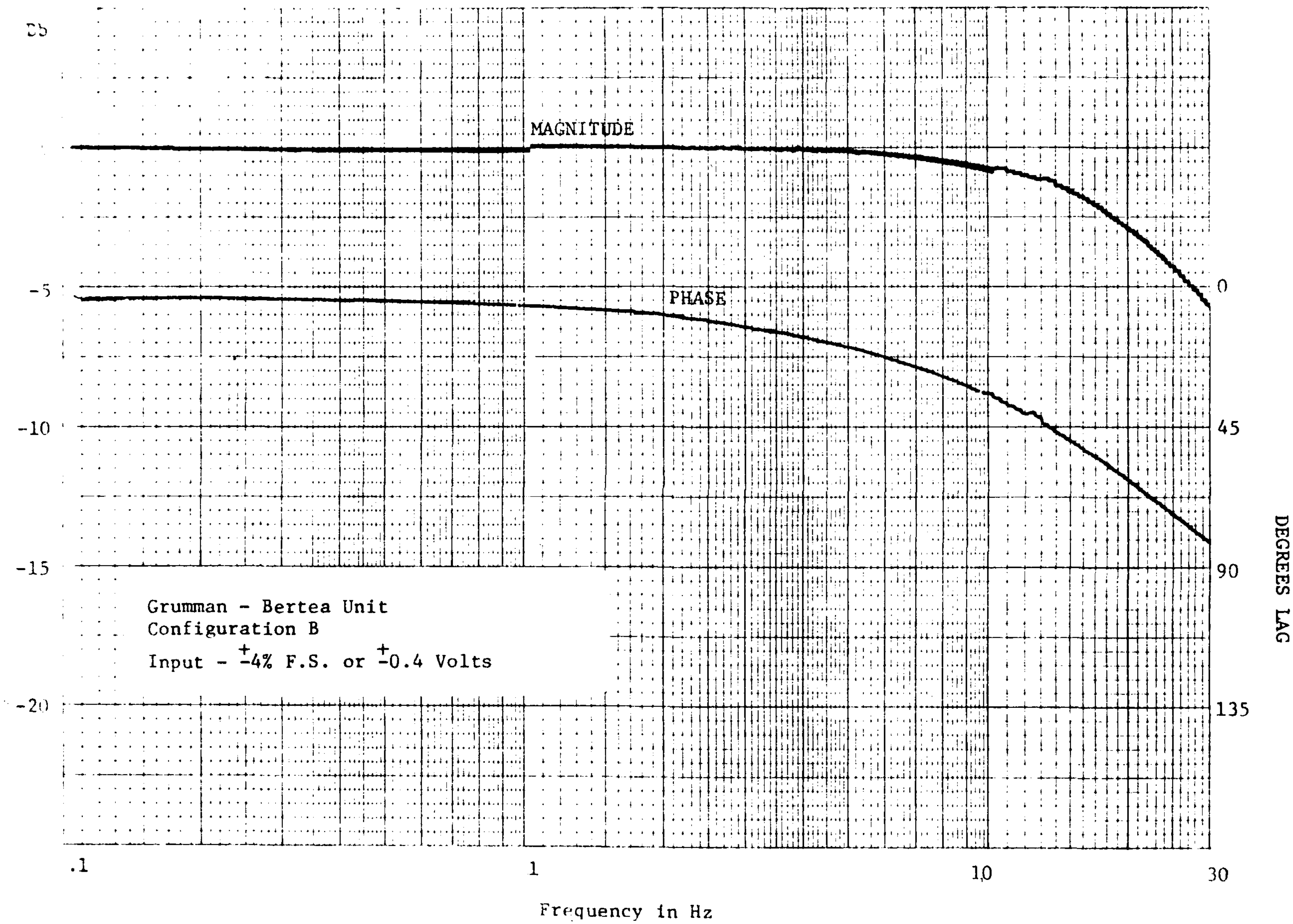



FIGURE 44 Frequency Response - Condition 1

TABLE 13

Frequency Response

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 4/18/79

TEST ITEM - Grumman - Bertea Unit
Configuration B

TEST - FREQUENCY RESPONSE

| Test Condition | Output 4% Full Scale -3 db Hz | -90° Hz |
|---|---|---|
| 1 | 21.0 | 35.0 |
| 2 | 20.0 | 34.0 |
| 3 | 19.0 | 31.0 |
| 4 | 20.0 | 33.0 |
| 5 | 20.0 | 31.0 |
| 6 | 21.0 | 33.0 |
| 7 | 18.0 | 31.0 |
| 8 | 18.0 | 31.0 |
| 9 | 19.0 | 32.0 |
| 10 | 19.0 | 33.0 |
| 11 | 18.0 | 32.0 |

### 3.7.2.4 Distortion

Table 14 lists the harmonic distortion measurements for test Conditions 1 through 11. For each test condition, 3 distortion measurements are listed, corresponding to 5 Hz, 10 Hz and 20 Hz. The input level used when making the measurements was 4% of the full scale input level and the same as that used to obtain the frequency response measurements. The table lists the distortion in terms of the % change from the baseline value of operating Condition 1. The baseline distortion values are less than 5% for all three frequencies. A harmonic distortion of 5% or less is difficult to visually detect on a sinusoidal signal.

The distortion percentage change from the baseline condition was a maximum of 1% for all test conditions and frequencies. This occurred with two channels electrically failed (Condition 3) and for frequencies of 10 and 20 Hz. For several test conditions the distortion reduced slightly from the baseline condition values.

No degradation of the signal characteristics with the different operating conditions is indicated by the test results of Table 14. The percent distortion levels (including the baseline values) indicate good signal fidelity for the actuator response. The baseline distortion for the 20 Hz measurements is slightly higher (4.4% vs 3.6%) for Configuration B compared to Configuration A. However, this change does not indicate significant performance changes due to the operation of the pressurization equalization feedback.

TABLE 14

Distortion

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 4/19/79

TEST ITEM - Grumman - Bertea Unit
Configuration B

TEST - DISTORTION

| Test Condition | Change of % distortion from baseline value | | |
|---|---|---|---|
| | % @ 5 Hz | % @ 10 Hz | % @ 20 Hz |
| 1 | Baseline Value* | Baseline Value** | Baseline Value*** |
| 2 | 0 | 0.10 | 0.30 |
| 3 | 0.20 | 1.00 | 1.00 |
| 4 | -0.30 | -0.30 | -0.50 |
| 5 | 0.10 | 0.80 | 0.80 |
| 6 | -0.20 | 0.10 | 0.80 |
| 7 | -0.50 | -0.20 | 0 |
| 8 | -0.10 | 0.20 | -0.50 |
| 9 | 0.10 | 0.30 | 0.60 |
| 10 | -0.70 | -0.50 | -0.60 |
| 11 | -0.10 | 0.30 | -0.70 |

*3.10% **3.40% ***4.40%

### 3.7.2.5 Hysteresis

Figure 45 shows the data recorded for measuring the hysteresis of Configuration B for Condition 1. The input level used was ±1% of the input for full actuator position. As shown on Figure 45, the hysteresis loop is that of a device with static friction in the control path.

Table 15 lists the hysteresis measured for the test Conditions 1 through 11 in terms of the actuator full scale input and in terms of the input required to generate full flow from the servovalve. The hysteresis measured is less than .36% for any test condition when expressed in terms of the actuator full scale stroke. In terms of the input required for generation of maximum flow from the servovalve, the percentage hysteresis is much higher and reaches a value of 46.8% for test Conditions 6 and 8.

For the condition of input offsets, (Conditions 6, 7, 8 and 9) the hysteresis is approximately twice as great as the normal operational configuration (Condition 1). This indicates that the effect of the offsets which cause the pressure equalization feedback to be effective (reducing the pressure gain of the servovalves) does increase the hysteresis of the system.

Compared to Configuration A, the hysteresis measured for Configuration B is somewhat greater for all test conditions. For Condition 1, the hysteresis for Configuration B is 60% greater than that measured for Configuration A.

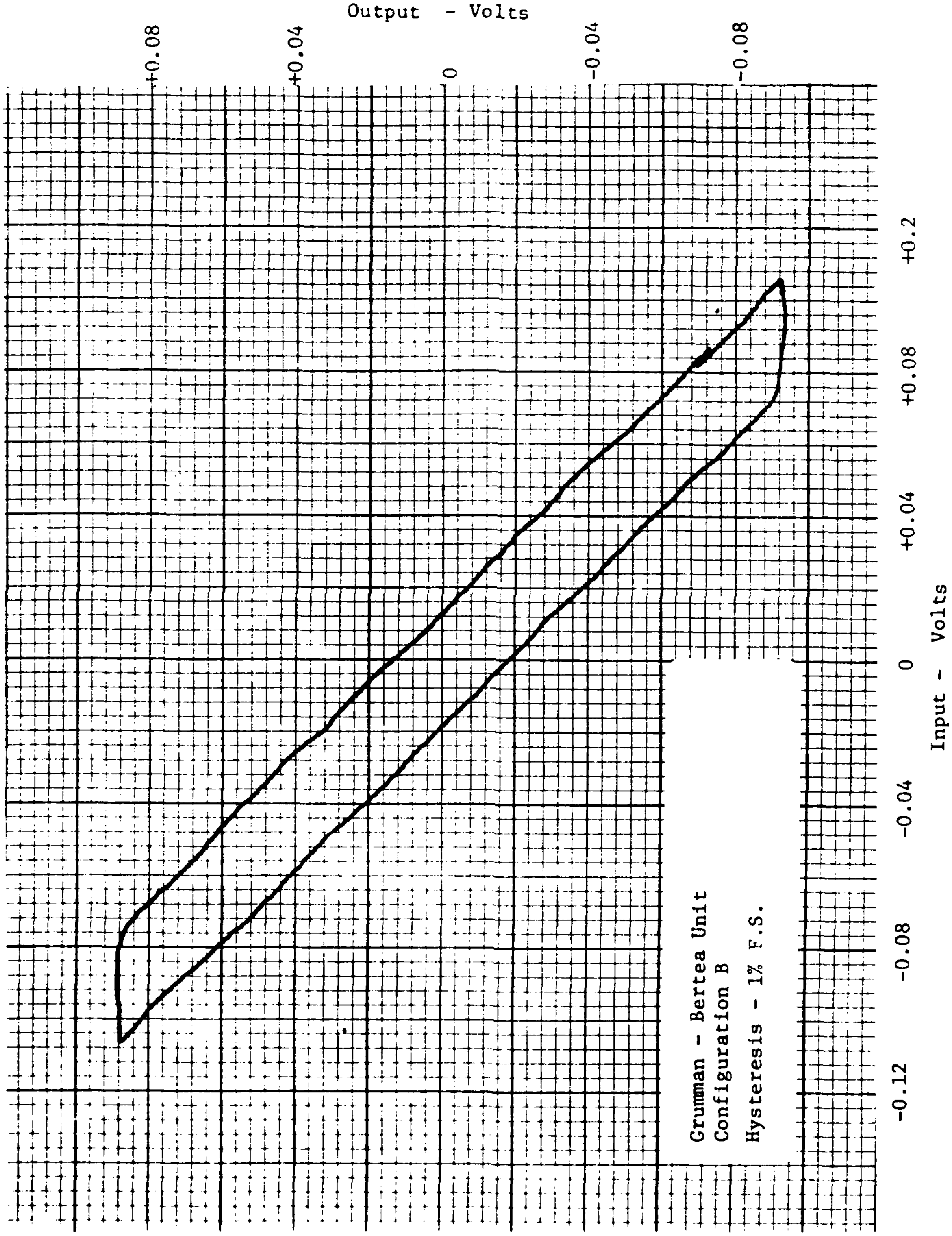



FIGURE 45 Hysteresis - Condition 1

TABLE 15

Hysteresis

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 4/19/79

TEST ITEM - Grumman - Bertea Unit
Configuration B

TEST - HYSTERESIS

| Test Condition | % Full Scale | % of $E_v$ Max |
|---|---|---|
| 1 | 0.16 | 20.80 |
| 2 | 0.18 | 23.40 |
| 3 | 0.24 | 31.20 |
| 4 | 0.18 | 23.40 |
| 5 | 0.26 | 33.80 |
| 6 | 0.36 | 46.80 |
| 7 | 0.28 | 36.40 |
| 8 | 0.36 | 46.80 |
| 9 | 0.32 | 41.60 |
| 10 | 0.16 | 20.80 |
| 11 | 0.16 | 20.80 |

3.7.2.6 Saturation Velocity

Figure 46 shows the data recorded for test Condition 1 in order to determine the saturated velocity of the Configuration B actuator output. Both the extend and the retract time traces for a step input of 9.2 volts (applied to the input of the demonstration unit) are shown. This input voltage was large enough to insure that the maximum flow to the actuator was obtained from the servovalve.

Table 16 lists the saturated extend and retract velocities for test Conditions 1 through 11. As with the Configuration A test results for saturation velocity, the test Condition 1 produced the highest saturation velocity. Conditions 2, 3, 4 and 5 with one or more channels either failed electrically or hydraulically, the saturation velocity is reduced from that of Condition 1. This is to be expected since the channels without failures are required to drag the failed channels along. This creates a load on the unfailed channel actuators and reduces the flow from the servovalves for those channels. For Condition 5, with two channels failed hydraulically, the saturation rate reduction from Condition 1 is 29%. Note that the saturation velocities for test Conditions 6, 7 and 8 with offset inputs to the control channels exhibit essentially the same saturation velocities as Condition 1 (normal operation).

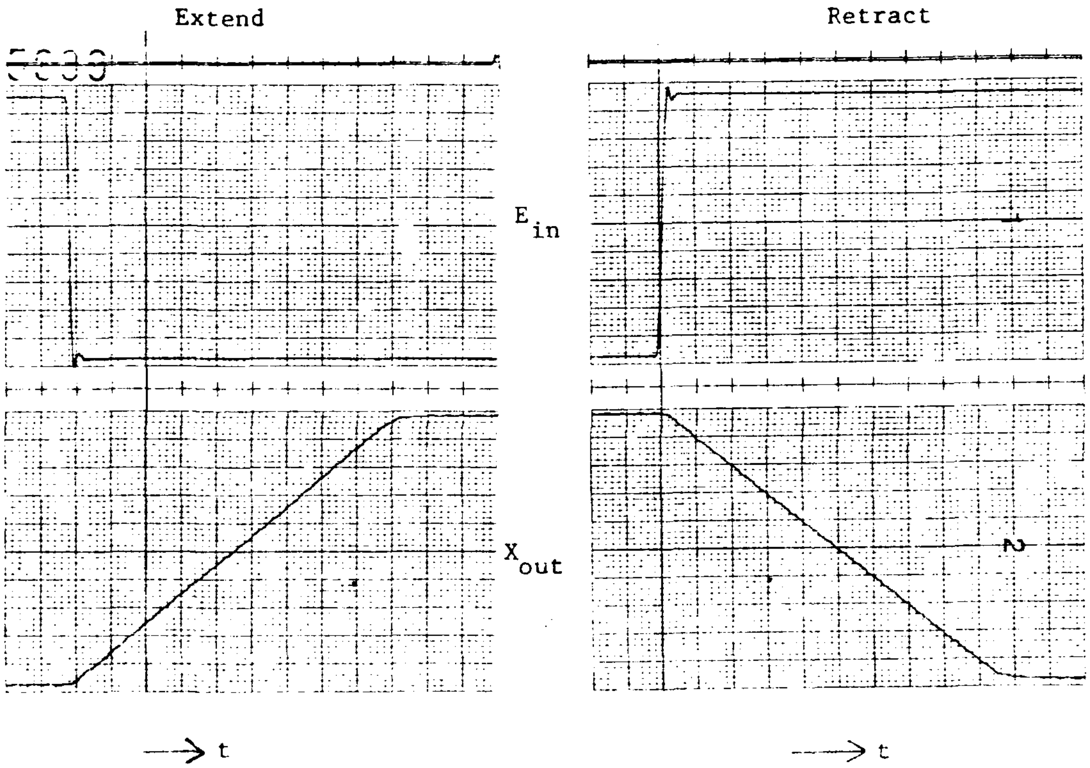
Compared to Configuration A, the Configuration B saturation rates are essentially the same for all test conditions. This indicates that the pressure equalization feedback has negligible effect on the maximum unloaded actuator rate.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM – Grumman - Bertea Unit
Configuration B

Date Prepared 4/25/79

TEST – Saturation Velocity - Condition 1




Maximum Amplitude Step Input

Scale: Input = 0.200 v/div
$X_{out}$ = 0.013 in/div
t = 200 div/sec

FIGURE 46 Saturation Velocity - Condition 1

TABLE 16

Saturation Velocity

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 4/19/79

TEST ITEM - Grumman - Bertea Unit
Configuration B

TEST - SATURATION VELOCITY

| Test Condition | Extend - in./sec. | Retract - in./sec. |
|---|---|---|
| 1 | 2.74 | 2.67 |
| 2 | 2.43 | 2.48 |
| 3 | 2.18 | 2.22 |
| 4 | 2.43 | 2.48 |
| 5 | 1.94 | 2.09 |
| 6 | 2.74 | 2.60 |
| 7 | 2.74 | 2.60 |
| 8 | 2.74 | 2.67 |
| 9 | 2.54 | 2.54 |
| 10 | 2.48 | 2.54 |
| 11 | 2.37 | 2.43 |

### 3.7.2.7 Linearity

Figure 47 shows the actuator output linearity measured for Configuration B and Condition 1. Since the linearity of the mechanization is primarily determined by the feedback transducers used with each control channel and the position loop gains of the individual channels, no change from the Configuration A results was expected. Figure 47 confirms the expected results. The linearity measured for all the operating conditions was essentially the same as that shown on Figure 47 and was within 1% full scale.

### 3.7.2.8 Step Response

Figures 48 through 53 show the extend and retract step response measurements for Conditions 1 through 11. The input level for these measurements was 4% of the input for maximum actuator position. This level, since it was a step input, was twice that required for a saturation of the servovalve. Therefore, until the actuator moved 50% of the total movement in response to the command step, the servovalve was saturated and the actuator moved at a saturation rate. The remaining 50% of the movement as shown on Figures 48 through 53 is unsaturated and indicates the transient response of the mechanization.

The results indicated by the Figures 48 through 53 are quite similar to those measured with Configuration A and indicate that the pressure equalization feedback as mechanized has no apparent effect on the unloaded step response of the mechanization.

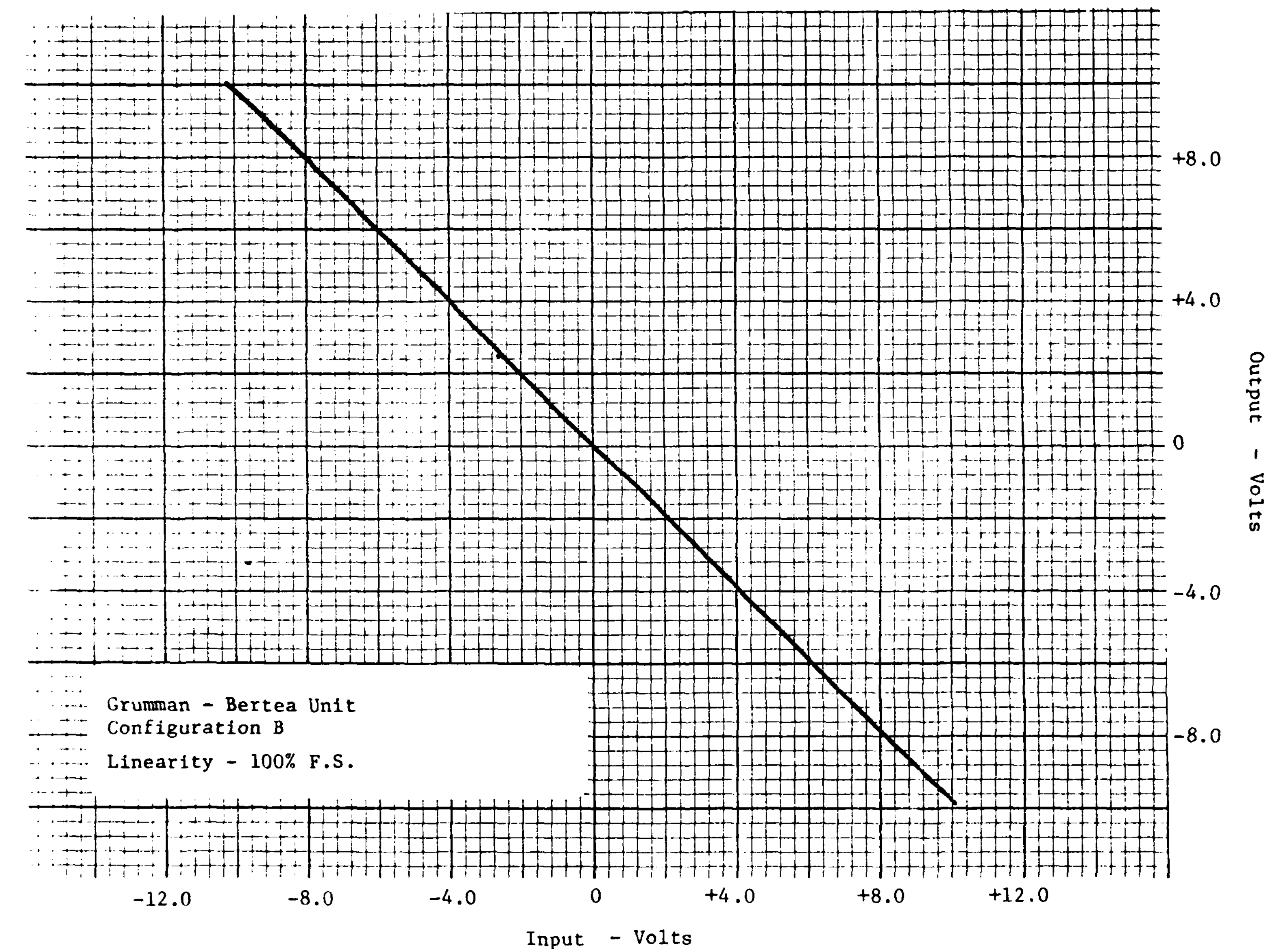



FIGURE 47 Linearity - Condition 1

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

TEST - Step Response - Conditions 1 & 2

Date Prepared 4/30/79

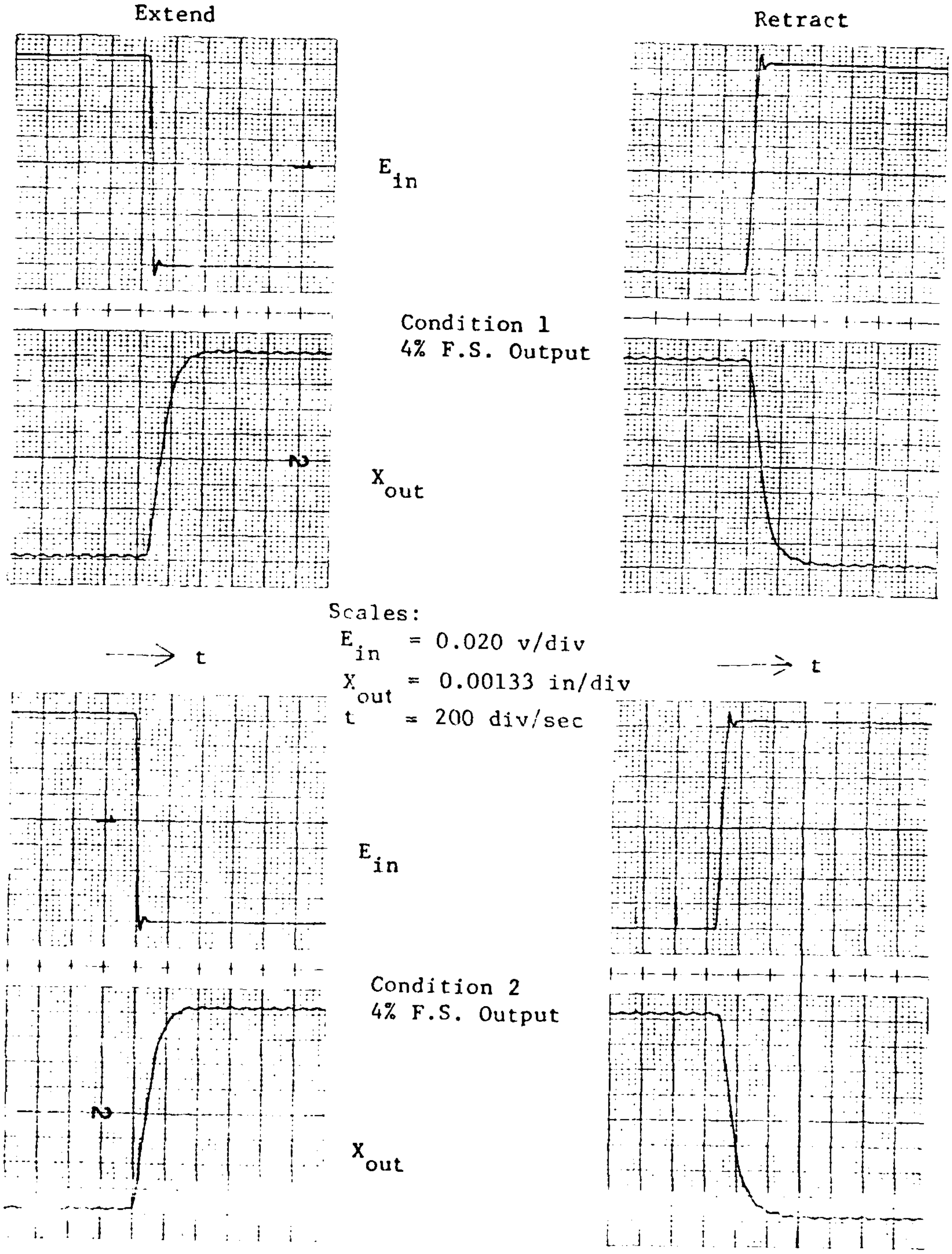



FIGURE 48 Step Response - Conditions 1 & 2

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

TEST - Step Response - Conditions 3 & 4

Date
Prepared 4/30/79

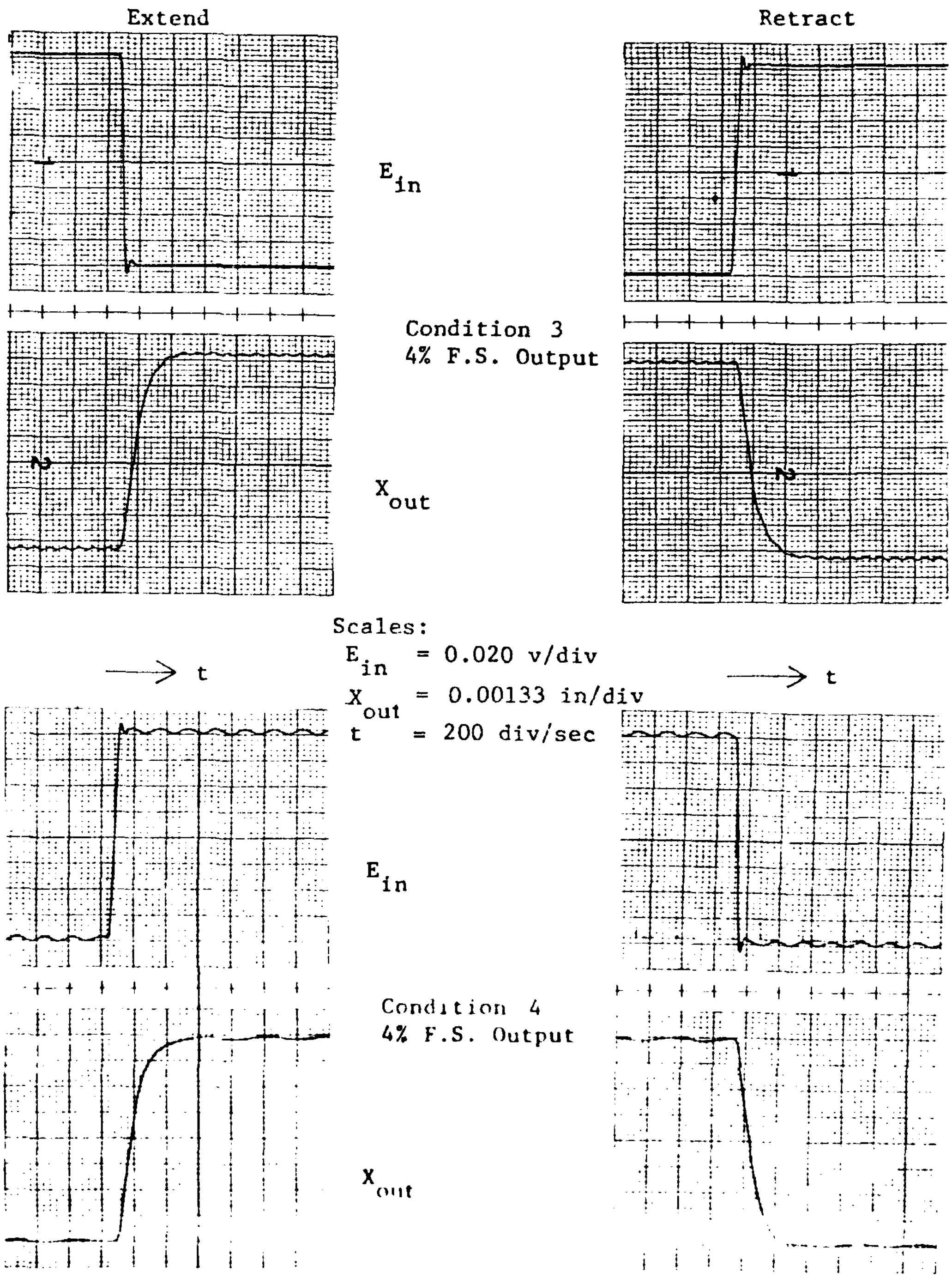



FIGURE 49 Step Response - Conditions 3 & 4

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date Prepared 4/30/79

TEST - Step Response - Conditions 5 & 6

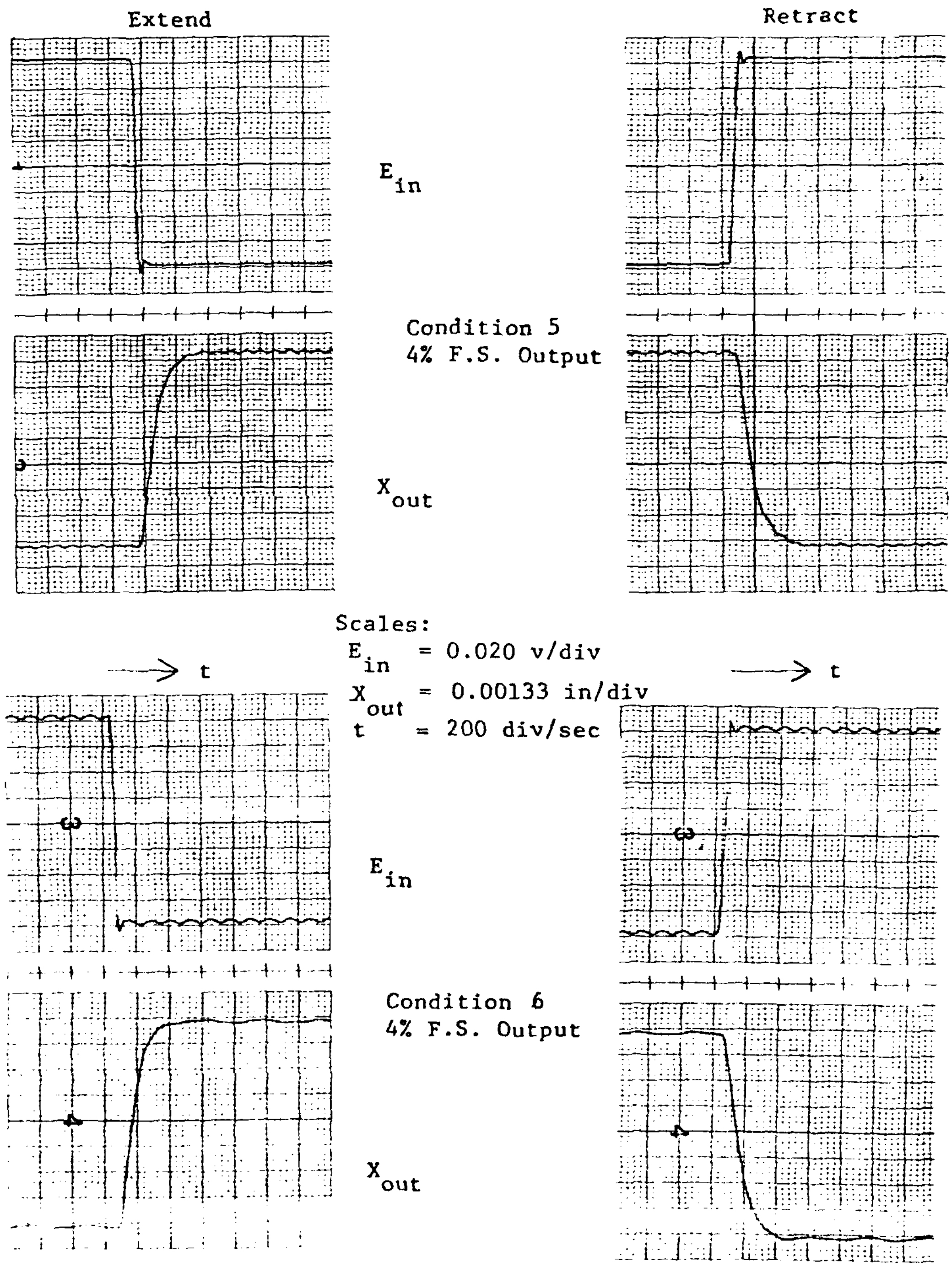



FIGURE 50 Step Response - Conditions 5 & 6

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 4/30/79

TEST - Step Response - Conditions 7 & 8

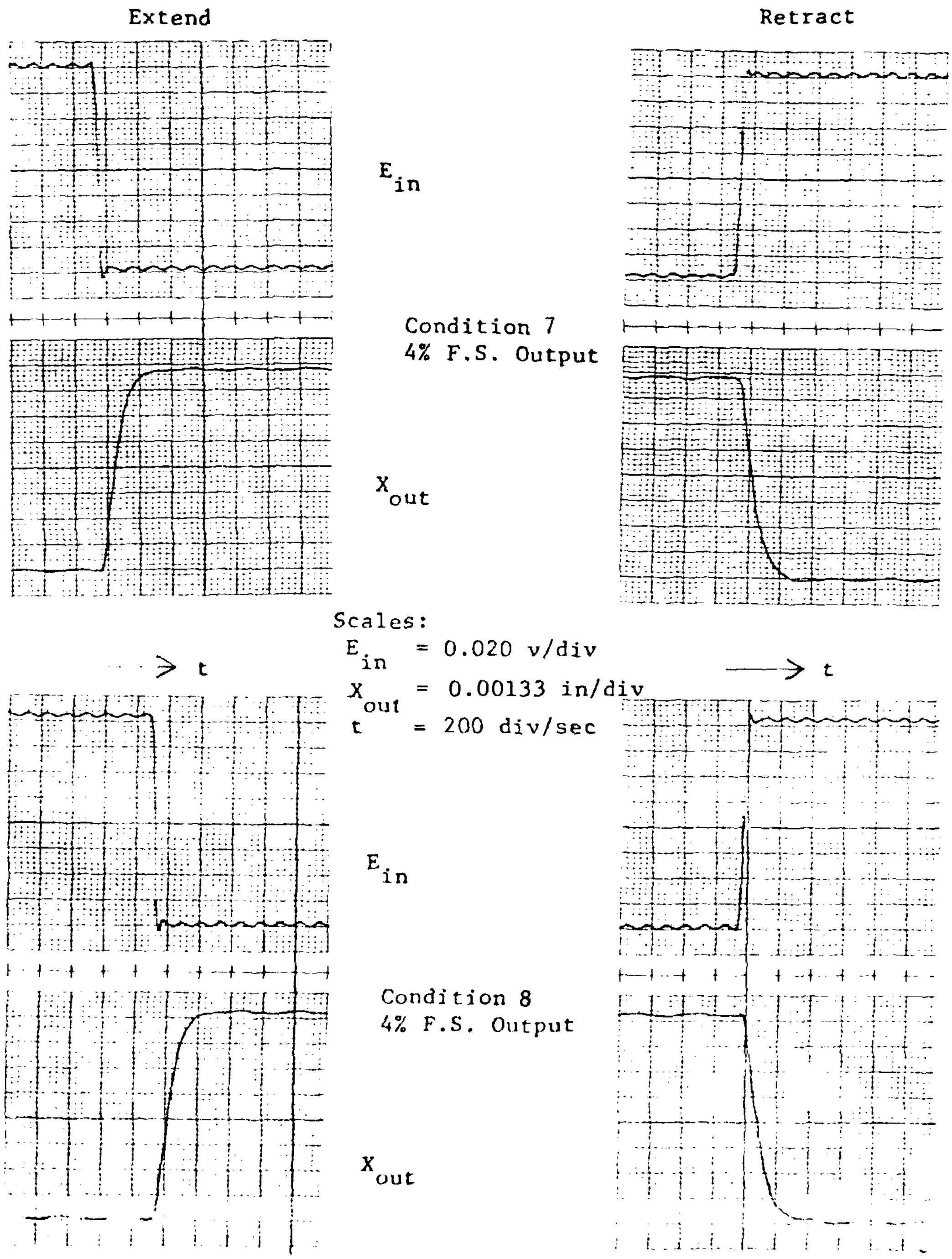



FIGURE 51 Step Response - Conditions 7 & 8

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date Prepared 4/30/79

TEST - Step Response - Conditions 9 & 10

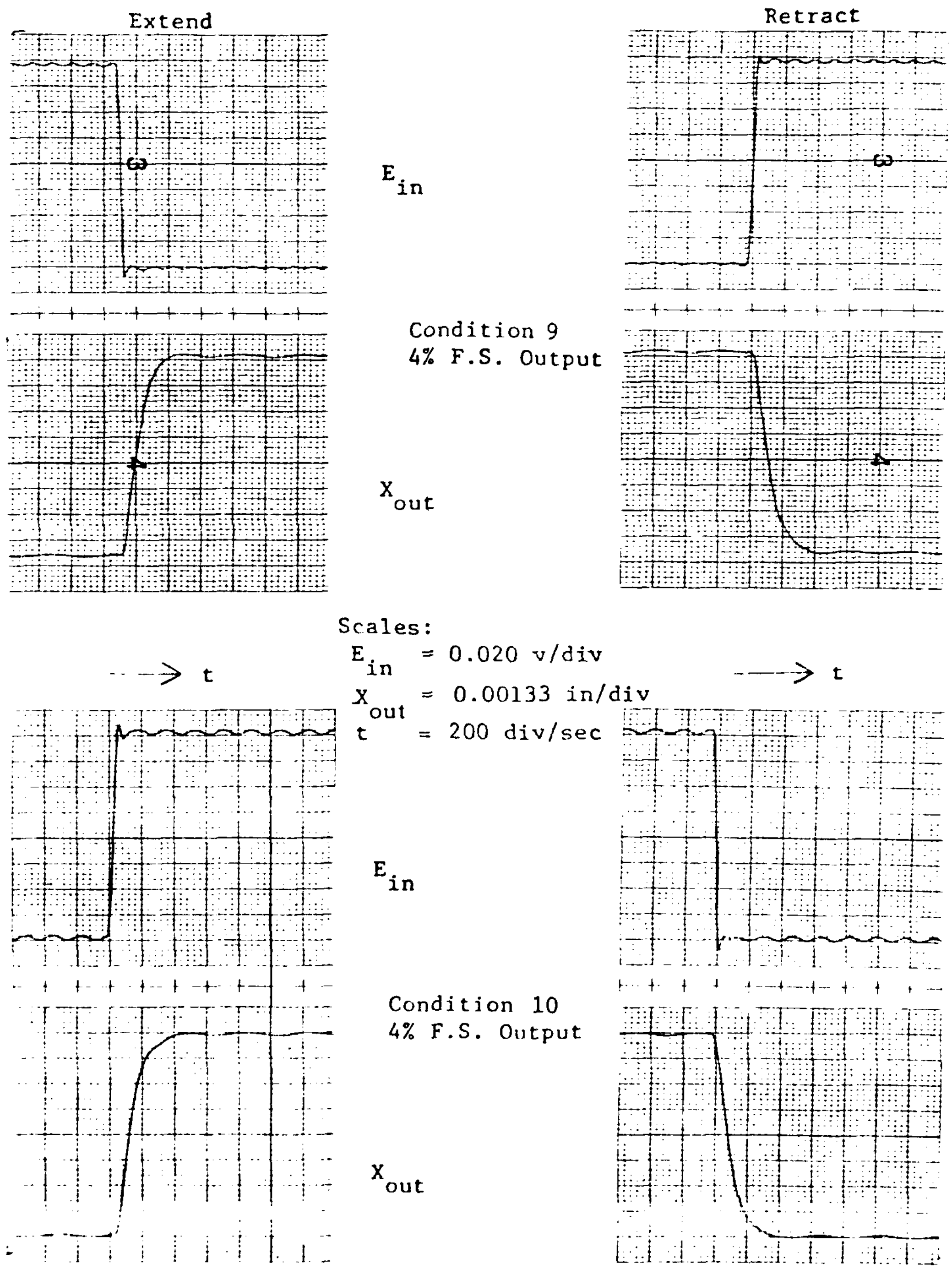


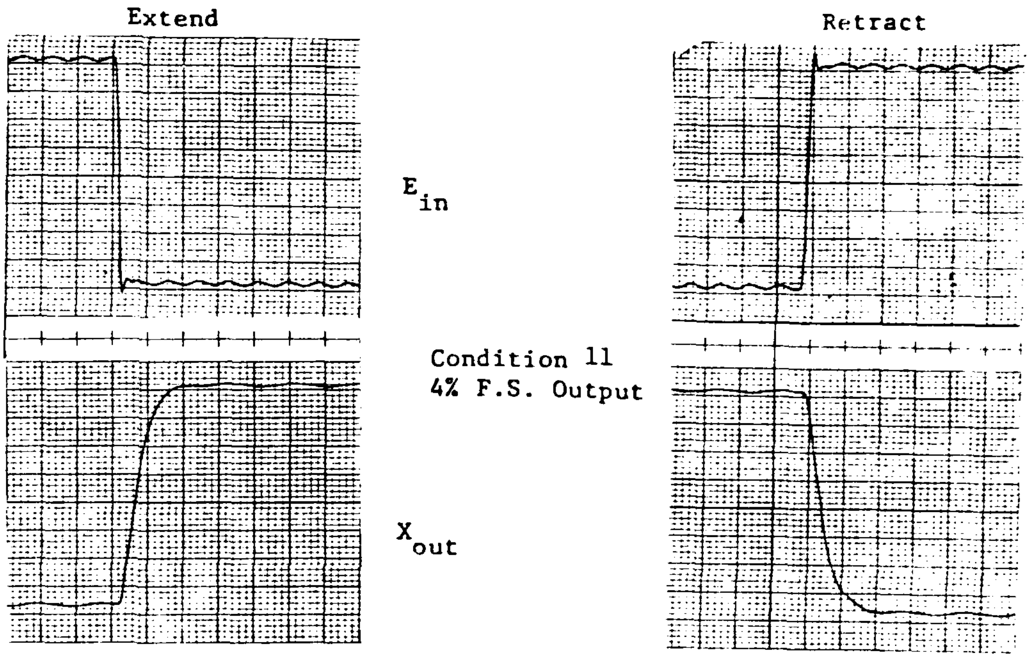

FIGURE 52 Step Response - Conditions 9 & 10

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

TEST - Step Response - Condition 11

Date
Prepared 4/30/79




Scales:

$\longrightarrow$ t

$E_{in}$ = 0.020 v/div

$X_{out}$ = 0.00133 in/div

t = 200 div/sec

$\longrightarrow$ t

FIGURE 53 Step Response - Condition 11

### 3.7.3 Failure Transients

Test Conditions 12 through 32 were used to establish the failure transient characteristics of Configuration B. The test results and test conditions are arranged in the following order:

| TEST | Test Conditions |
|---|---|
| Electrical Input Loss Transient | 12, 13, 14, 15 |
| Electrical Hardover Input Transient (with actuator initially at rest) | 16, 17, 18, 19, 20, 21 |
| Electrical Hardover Input Transient (with actuator initially cycling) | 22, 23 |
| Simultaneous Hardover Input Transient | 24, 25, 26, 27 |
| Slowover Electrical Input Transient | 28, 29 |
| Hydraulic Failure Transient | 30, 31, 32 |

The test results in the following sub-sections are presented as listed above.

#### 3.7.3.1 Electrical Input Loss Transient

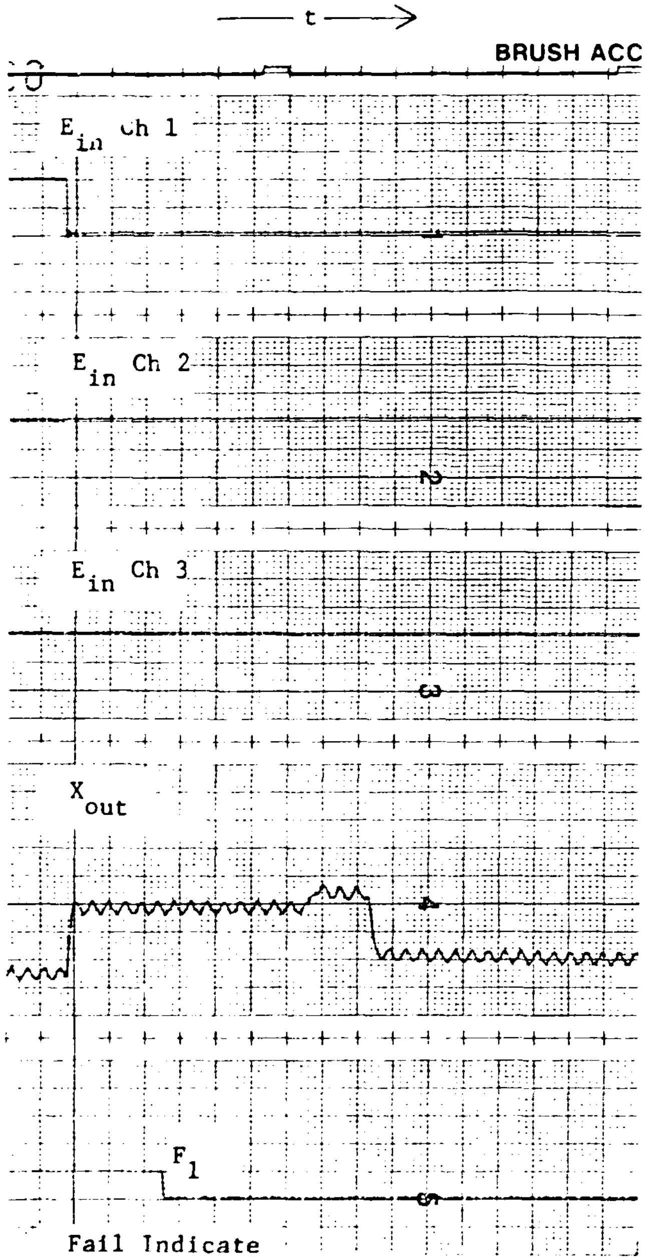
Figure 54 shows the effect of grounding of the input to channel 1 with the actuator initially commanded to a 50% extend position. Failure of the input (a change to 0 volts input by grounding the input of the channel) is displayed on the channel 1 data channel of Figure 54. The change of position of the actuator is shown on the fourth data channel from the top. The activation of the failure removal warning light is shown on the bottom data channel of Figure 54. The deviation of the actuator position is .63% of the total actuator stroke with the first failure. After the failed channel is depressurized, the null offset from the original null position is .21% of the total actuator stroke. Figures 55 and 56 show the effect of a second and third channel input grounding. The actuator deviation for the second failure is .81%

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 5/31/79

TEST - Failure Transients - Condition 12 (1st Failure)




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.0007 in/div
t = 50 div/sec

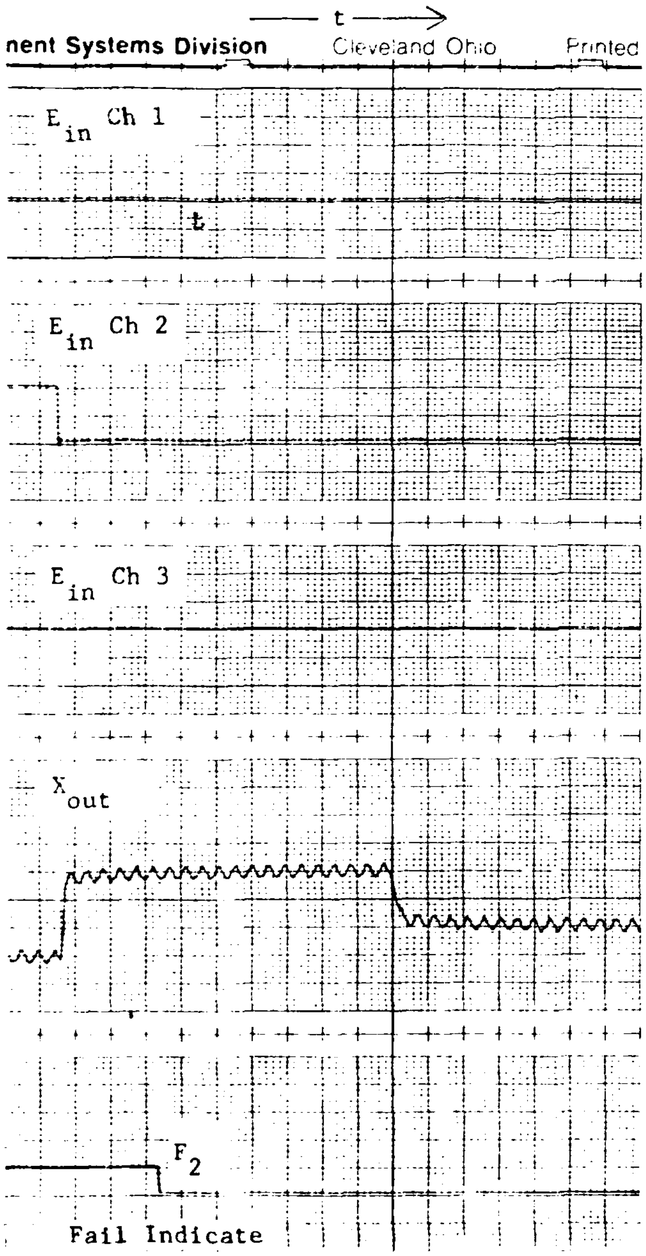
FIGURE 54 Failure Transients - Condition 12 (1st Failure)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration 15

Date
Prepared 5/31/79

TEST - Failure Transients - Condition 12 (2nd Failure)




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.0007 in/div
t = 50 div/sec

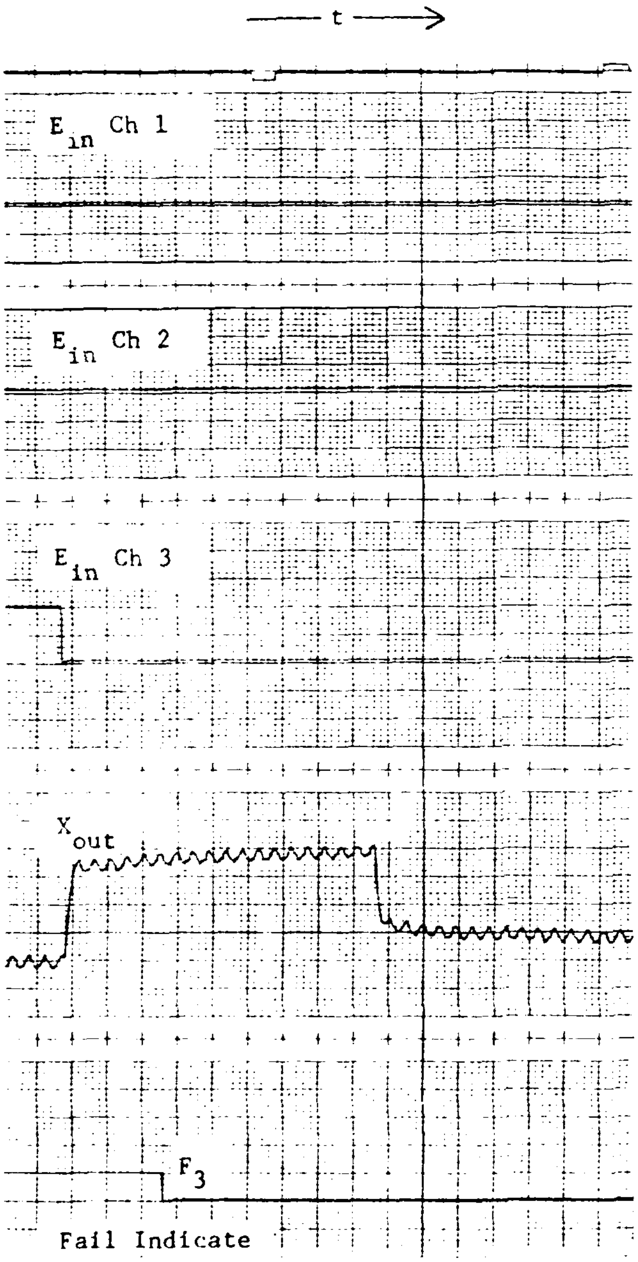
FIGURE 55 Failure Transients - Condition 12 (2nd Failure)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 5/31/79

TEST - Failure Transients - Condition 12 (3rd Failure)




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.0007 in/div
t = 50 div/sec

FIGURE 56 Failure Transients - Condition 12 (3rd Failure) of the total actuator stroke and the null offset is .31% of the total actuator stroke. For the third failure, the deviation and null offset are .92% and .24% respectively. As shown on Figures 54, 55 and 56, the time delay of the failure logic was .85 seconds for the test evaluation.

Figures 57, 58 and 59 show the effect of sequentially grounding the inputs to channels 1, 2 and 3 respectively with the actuator initially commanded to a 50% retract position. For the first channel (channel 1) the actuator output deviation was .65% of the full scale actuator output and no null shift occurred. For the second channel failure (channel 2) the output deviation was .30% and the null offset was .10% of the full scale actuator output. For the third failure, the output deviation was .75% and the null shift .30% of the full actuator output. As with Configuration A, the failure logic arbitrarily disconnected channel 3 after the third failure. The failure removal time delay varied between .85 to 1.1 seconds for the three failures.

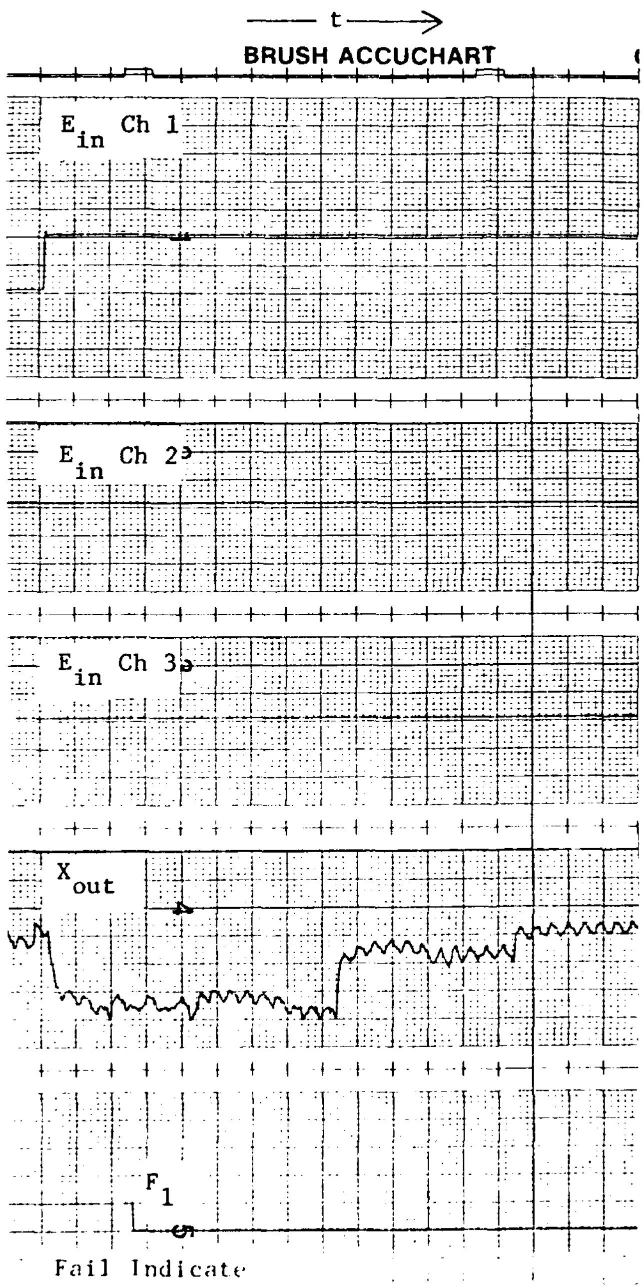
The transient deviation characteristics shown on Figures 54 through 59 are quite similar to the deviations which occurred for the same test conditions with Configuration A. This result was expected. Grounding of an input with the actuator commanded to a position away from null is similar to injecting a hardover failure into that channel. For hardover inputs, the failure detection circuitry would not show different detection characteristics between having the pressure equalization feedback connected.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date Prepared 5/31/79

TEST - Failure Transients - Condition 13 (1st H.O.)




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.0007 in/div
t = 50 div/sec

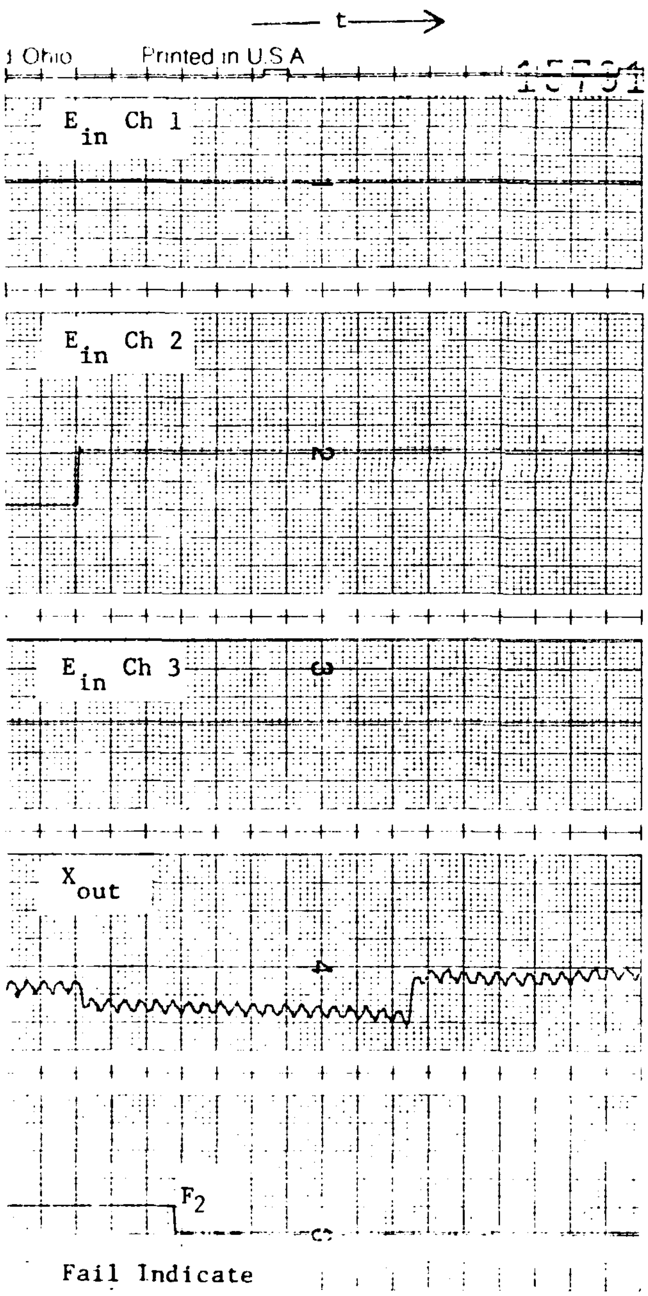
FIGURE 57 Failure Transients - Condition 13 (1st H.O.)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 6/1/79

TEST - Failure Transients - Condition 13 (2nd H.O.)




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.0007 in/div
t = 50 div/sec

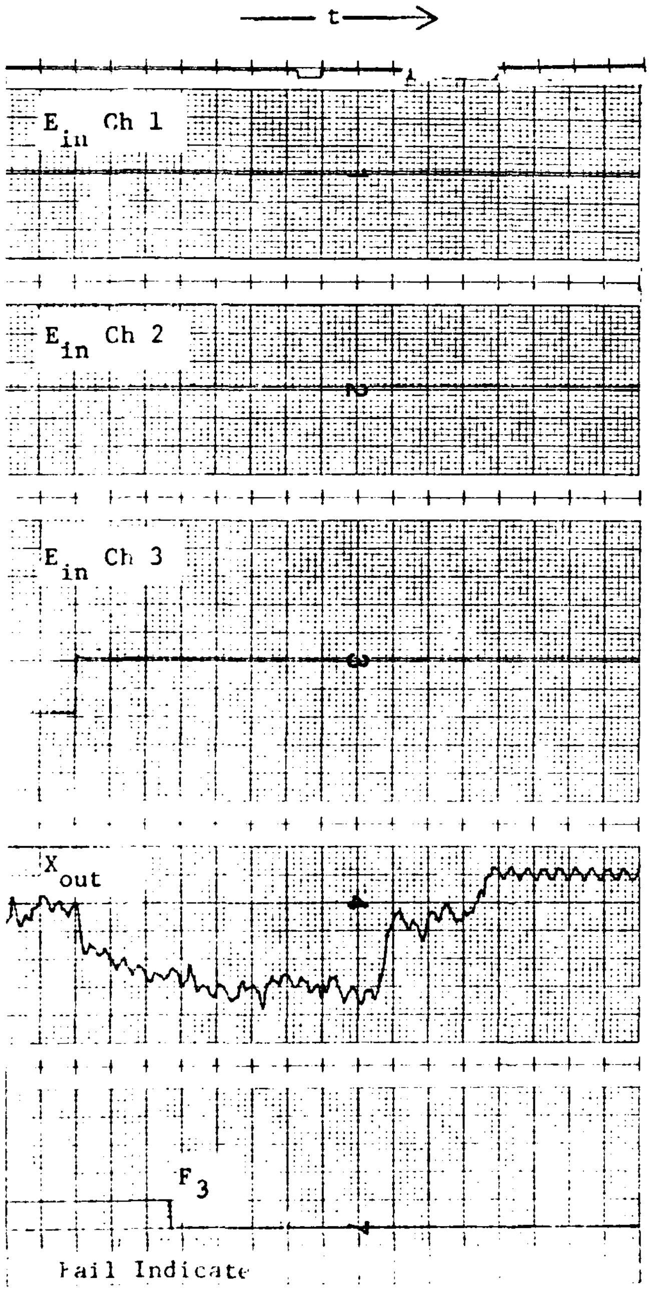
FIGURE 58 Failure Transients - Condition 13 (2nd H.O.)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date Prepared 6/1/79

TEST - Failure Transients - Condition 13 (3rd H.O.)




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.0007 in/div
t = 50 div/sec

FIGURE 59 Failure Transients - Condition 13 (3rd H.O.)

Figures 60, 61 and 62 show the effect of sequential grounding of the command inputs to the control channels while the actuator is being cycled at 10 Hz. Figure 60 shows the actuator output change being reduced to 77% of the "no failure" amplitude upon grounding of the channel 1 input. For a subsequent grounding of the input to channel 2, as shown on Figure 61, the actuator output is reduced to 43% of that before the second failure and to 33% of the amplitude with no failures. For the third channel input grounding, Figure 62 shows the output of the actuator responding slightly to channel 4 of the system, with an amplitude of 10% of the "no failure" amplitude. Note that the fail indicate data channel on the bottom of Figures 60, 61 and 62 shows that the failure logic does not detect the failures and cause depressurization of the failed channels. The control channels with grounded inputs fight the channels with input commands and cause the output amplitude response to deteriorate with each failure.

This result is similar to the Configuration A test results for the same test condition. The connection of the pressure equalization feedback network has no apparent effect on the ability of the failure logic to detect the input failure at a 10 Hz input frequency.

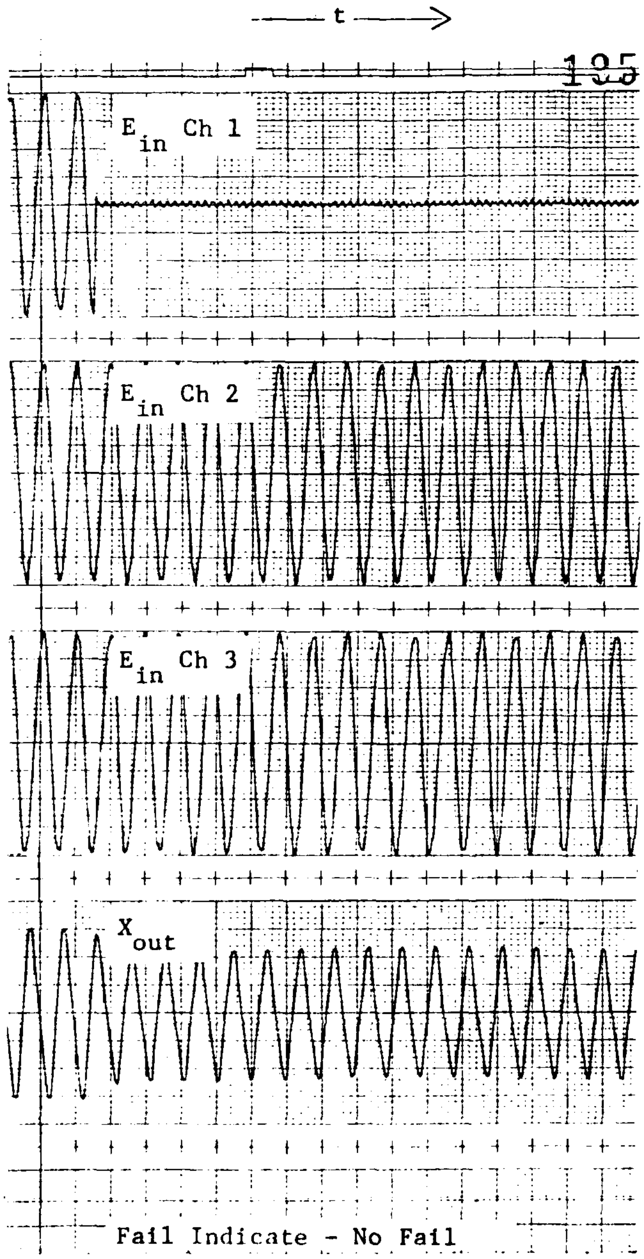
Figures 63, 64 and 65 show the effect of sequential grounding of the command inputs to the control channels while the actuator is being cycled at .5 Hz. Figure 63 shows the actuator output change resulting from the grounding of the input to channel 1. The failure is detected by the failure logic and channel 1 is depressurized. The amplitude deviation is a temporary reduction to 83% of the amplitude before the failure and then a return to 100% of the amplitude before the failure after channel 1 is

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 6/6/79

TEST - Failure Transients - Condition 14 (1 Ch Grounded)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.0033 in/div
t = 50 div/sec

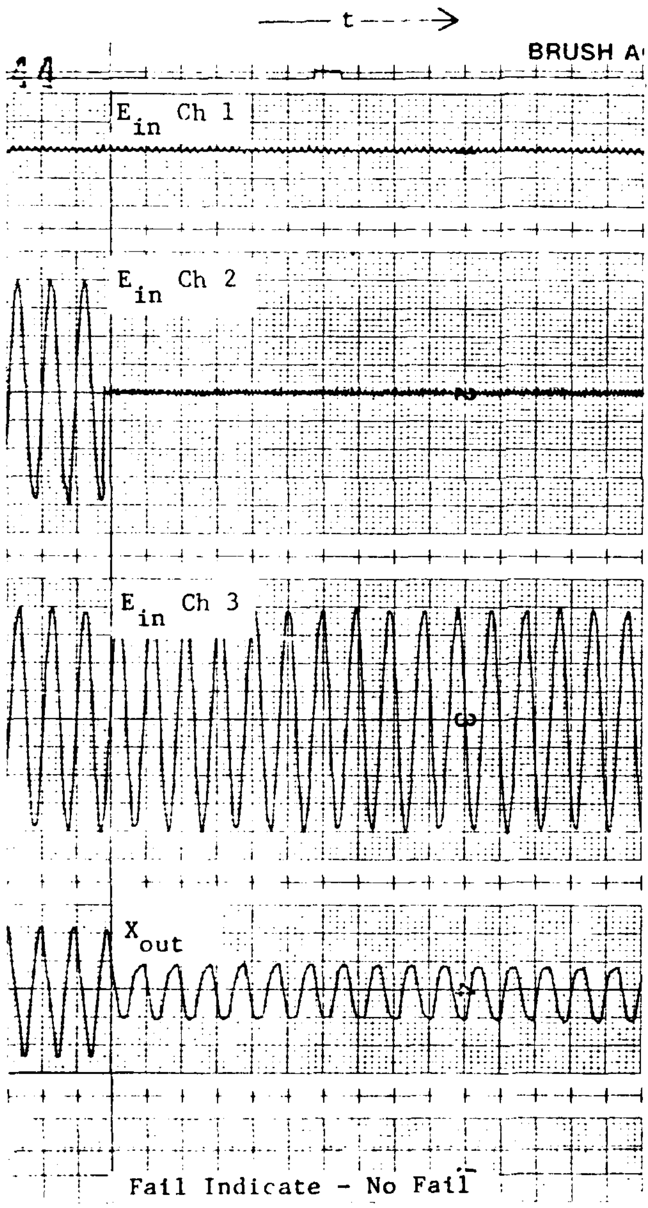
FIGURE 60 Failure Transients - Condition 14 (1 Ch Grounded)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date Prepared 6/6/79

TEST - Failure Transients - Condition 14 (2 Chs. Grounded)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.0033 in/div
t = 50 div/sec

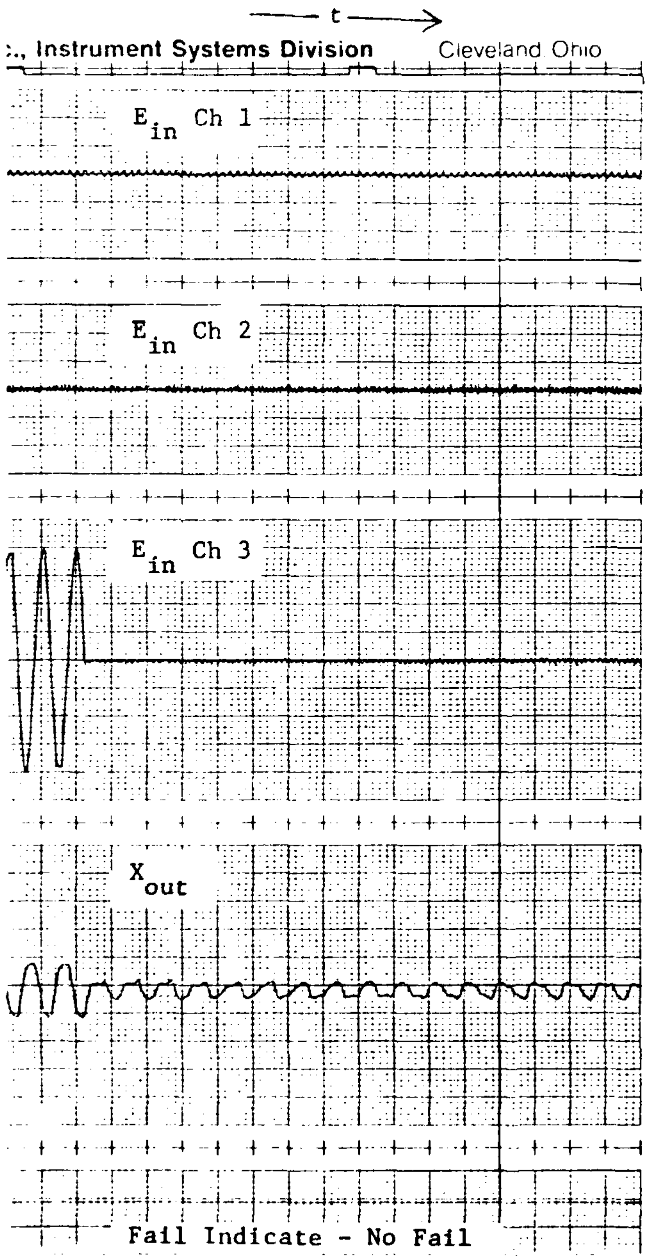
FIGURE 61 Failure Transients - Condition 14 (2 Chs. Grounded)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 6/6/79

TEST - Failure Transients - Condition 14 (3 Chs. Grounded)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.0033 in/div
t = 50 div/sec

FIGURE 62 Failure Transients - Condition 14 (3 Chs. Grounded)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 6/5/79

TEST - Failure Transients - Condition 15 (1 Ch Grounded)

Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.0033 in/div
t = 20 div/sec

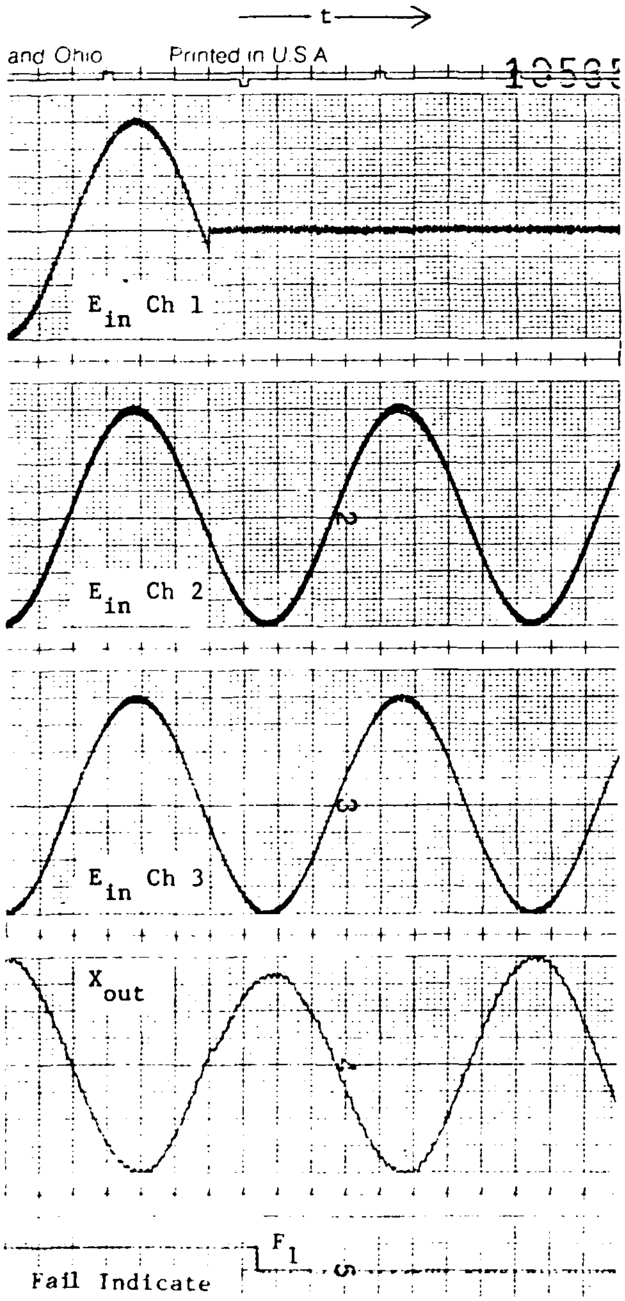



FIGURE 63 Failure Transients - Condition 15 (1 Ch Grounded)

depressurized. The grounding of the input to channel 2 after a failure of channel 1 is shown on Figure 64. As with the first failure, the failure logic detects the failed channel and depressurizes it. Until the failed channel 2 is depressurized, it fights channels 3 and 4, causing a temporary reduction of the output amplitude of 25% of the amplitude before failure. The grounding of the channel 3 input after a failure of channel 1 and 2 is shown on Figure 65. The failure logic does not latch for this test input and the actuator output continues to move at a greatly reduced amplitude. Since the failure logic shows some cycling on Figure 65, actual depressurization of the channel 3 (or 4) is not assured.

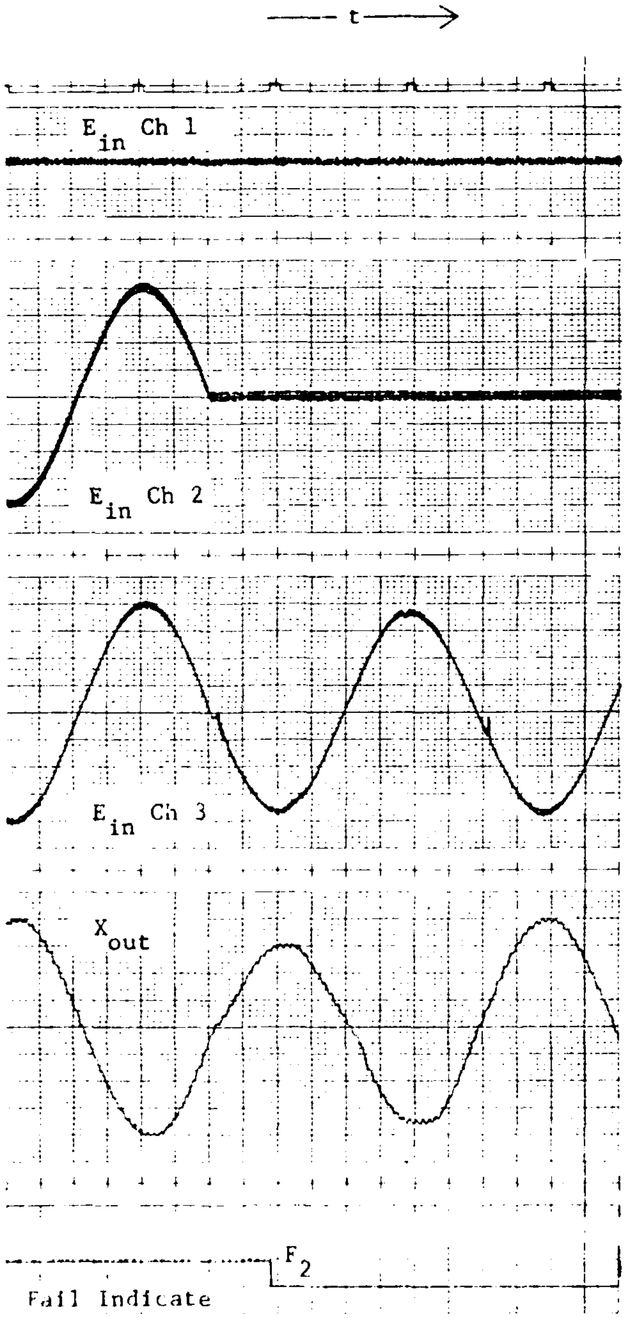
This .5 Hz test input was not used for the Configuration A evaluation. The .5 Hz input does demonstrate that when the dynamic characteristics of the failure logic allow failure detection at a particular frequency, the output of the actuator does not change significantly. Without failure detection (as occurs with the 10 Hz input) the force fight between failed and unfailed channels creates a severe actuator output degradation.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 6/5/79

TEST - Failure Transients - Condition 15 ((2 Chs. Grounded)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.0033 in/div
t = 20 div/sec

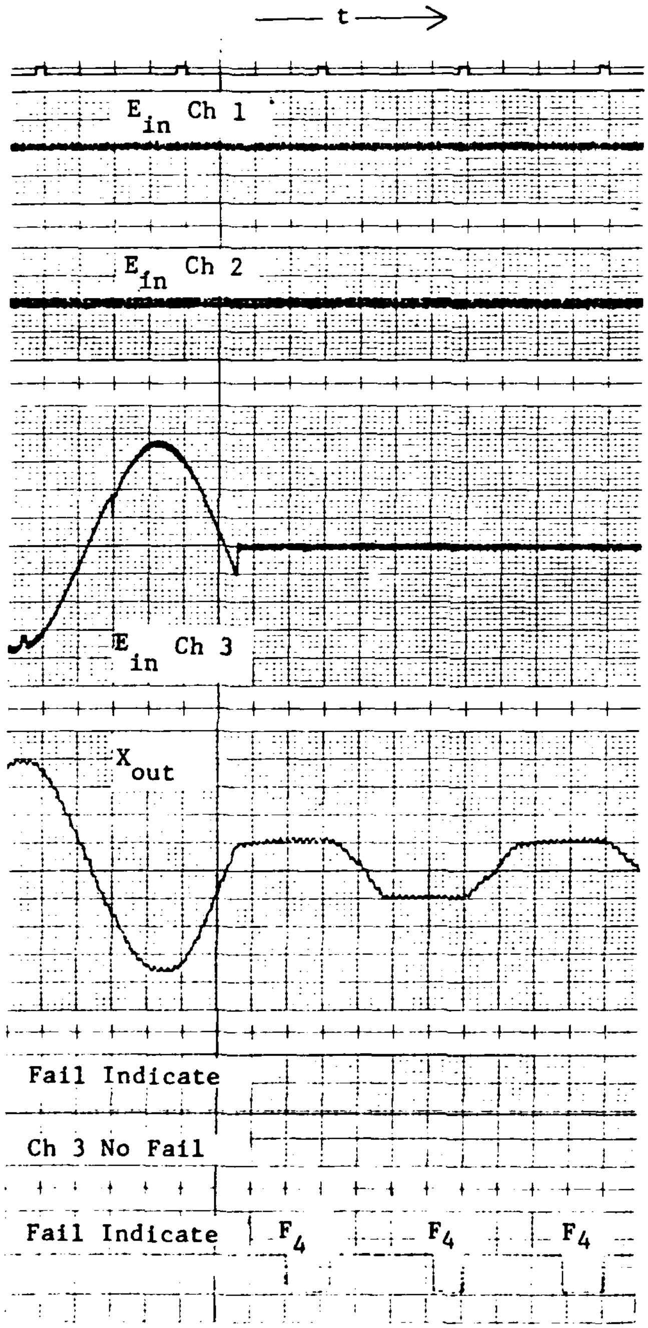
FIGURE 64 Failure Transients - Condition 15 (2 Chs. Grounded)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 6/5/79

TEST - Failure Transients - Condition 15 (3 Chs. Grounded)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.0033 in/div
t = 20 div/sec

FIGURE 65 Failure Transients - Codntiion 15 (3 Chs. Grounded)

### 3.7.3.2 Hardover Input Transient

Figures 66, 67 and 68 show the effect of a positive 10 volt step applied sequentially to channels 1, 2 and 3. The output deviation of the actuator is shown on the fourth data channel from the top of each figure. Activation of the failure warning lights is shown on the bottom data channel. The actuator output deviation for the first step input is shown on Figure 66 and is .45% of the total actuator stroke with a time duration of .85 seconds. The null offset after the channel is depressurized by the failure logic is .10% of the actuator full scale output. As shown on Figure 66, the failure logic takes .25 seconds to vote a failed channel as occurring and activate a fail indicate light. An additional .6 seconds is required to depressurize the failed channel.

Figure 67 shows the actuator deviation for a second hardover input applied to the system. The output deviation resulting from the hardover input applied to channel 2 is .3% of the actuator total stroke. The null offset after depressurization of channel 2 is .10% of the actuator full scale output. Figure 68 shows the actuator output deviation of .65% of the total actuator stroke resulting from a third hardover failure injected into channel 3. The failure is detected and channel 3 arbitrarily depressurized.

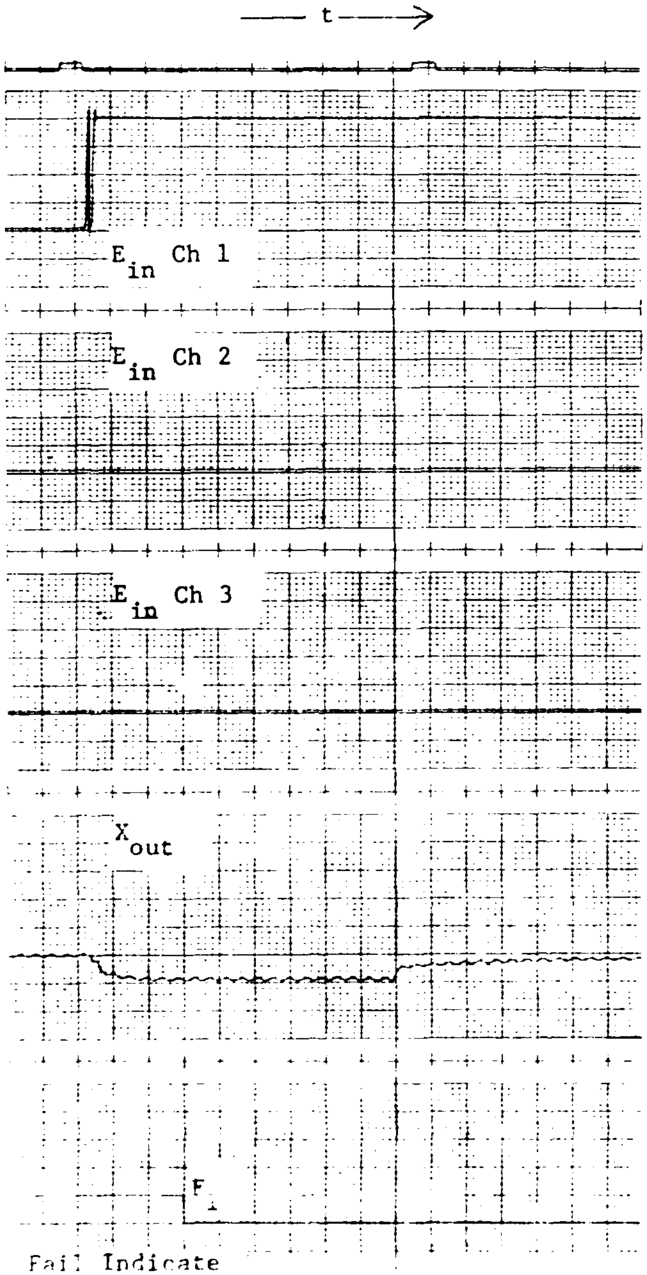
The actuator deviations and duration for Configuration B occurring with positive hardover inputs are similar to those measured for Configuration A with the same test conditions.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 5/29/79

TEST - Failure Transients - Condition 16 (1st H.O.)




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.0013 in/div
t = 50 div/sec

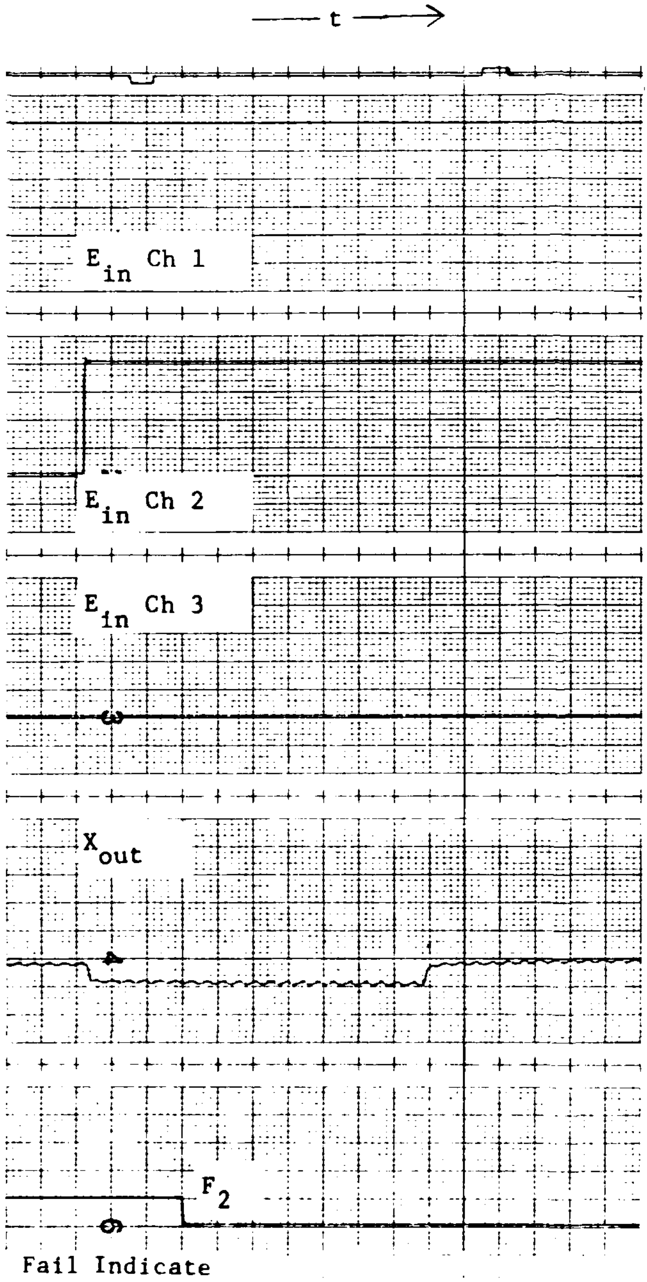
FIGURE 66 Failure Transients - Condition 16 (1st H.O.)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 5/29/79

TEST - Failure Transients - Condition 16 (2nd H.O.)




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.0013 in/div
t = 50 div/sec

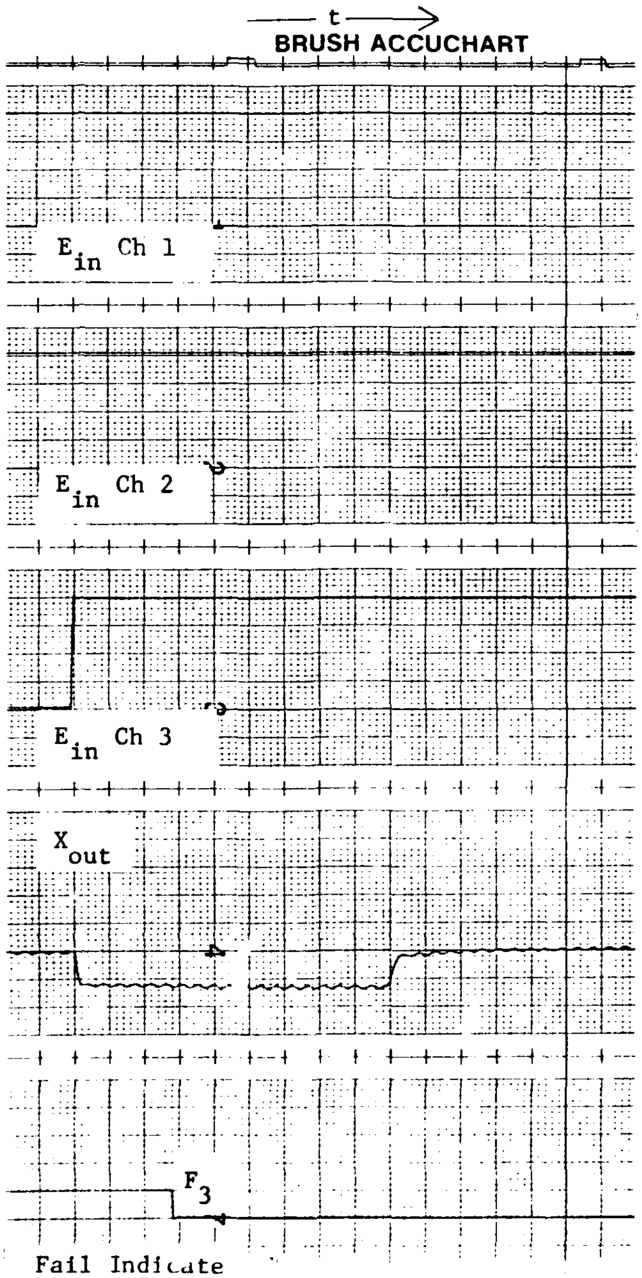
FIGURE 67 Failure Transients - Condition 16 (2nd H.O.)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 5/29/79

TEST - Failure Transients - Condition 16 (3rd H.O.)




Scale: $E_{in}$ = 0.500 v/div
Xout = 0.0013 in/div
t = 50 div/sec

FIGURE 68 Failure Transients - Condition 16 (3rd H.O.)

Figures 69, 70 and 71 show the actuator deviations occurring with sequential application of negative hardover inputs into channels 1, 2 and 3, respectively. Figure 69 shows the deviation occurring with a negative hardover input into channel 1. The actuator deviation is .60% of the full scale actuator stroke. The activation of the 100% force capability for channel four is apparent from the actuator deviation characteristic. The null offset after depressurization of channel 1 and the activation of channel 4's higher force limit, is .15% of the full scale actuator output.

The second hardover input into channel 2 results in an output deviation of 1.00% of the full scale actuator output and a null offset of .4% of the full scale actuator output. The third negative hardover input applied to channel 3 results in an immediate deviation of 1.6% of the full scale actuator stroke.

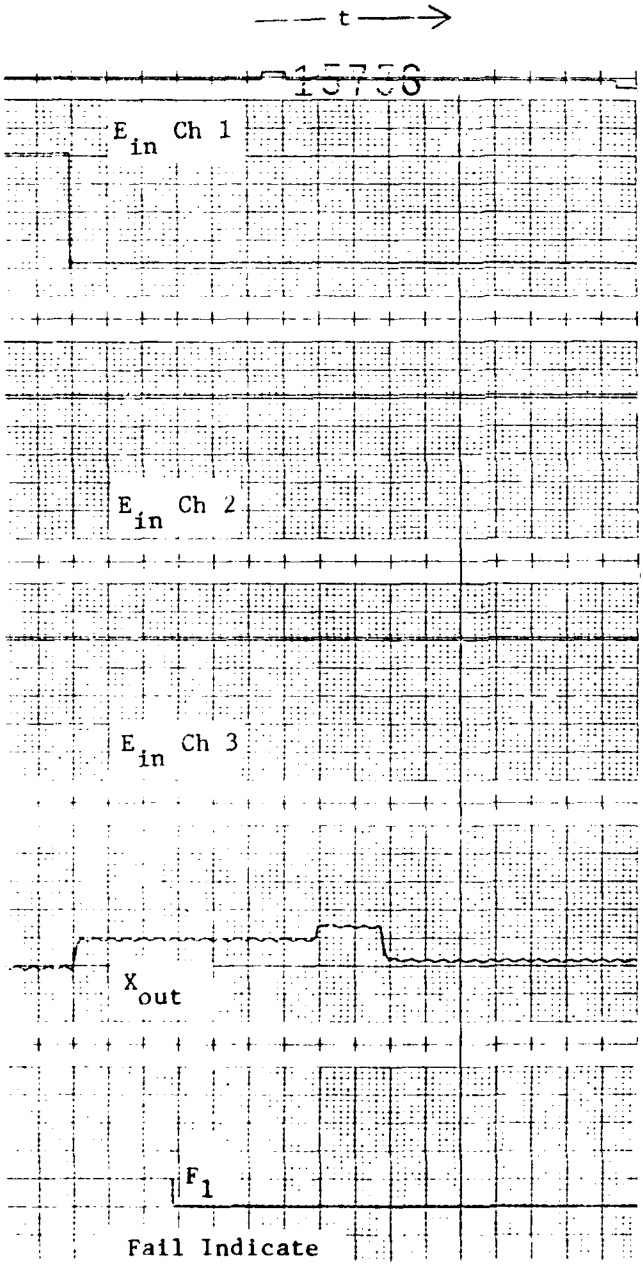
Note, that as with Configuration A, the hardover inputs shown on Figures 66 through 71 are not applied to channel 4. Since channel 3 is arbitrarily depressurized upon the third injected failure, the actuator output does not go hardover with the third failure. If the third failure had been injected into channel 4, depressurization of channel 3 would allow channel 4 to drive the actuator output hardover. To prevent hardover inputs from driving the actuator output hardover after three failures, an additional channel would be required in order to provide the necessary logic for a correct failure vote.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 6/8/79

TEST - Failure Transients - Condition 17 (1st H.O.)




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.0013 in/div
t = 50 div/sec

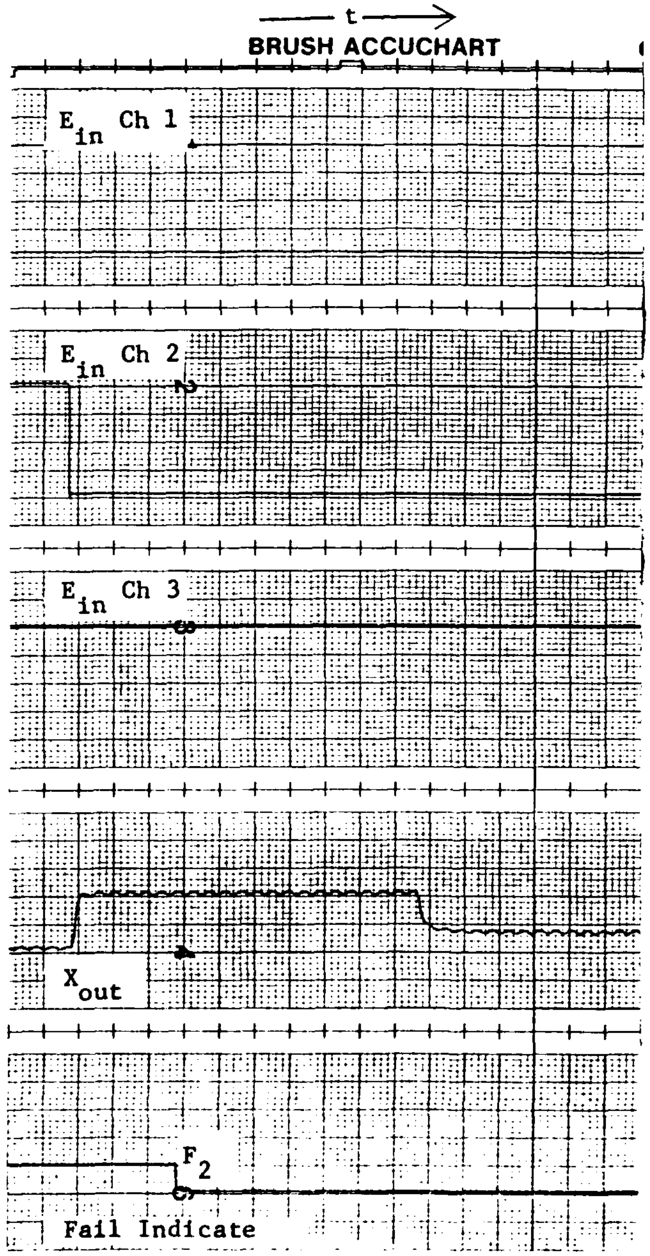
FIGURE 69 Failure Transients - Condition 17 (1st H.O.)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 6/8/79

TEST - Failure Transients - Condition 17 (2nd H.O.)




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.0013 in/div
t = 50 div/sec

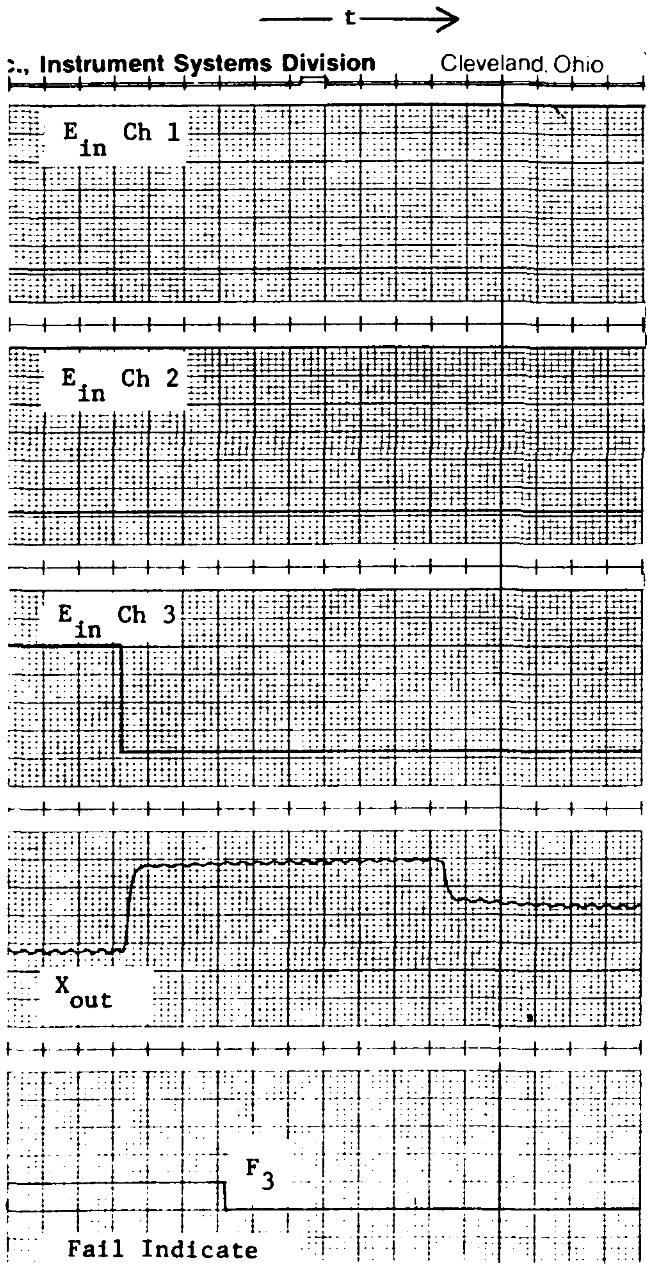
FIGURE 70 Failure Transients - Condition 17 (2nd H.O.)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 6/8/79

TEST - Failure Transients - Condition 17 (3rd H.O.)




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.0013 in/div
t = 50 div/sec

FIGURE 71 Failure Transients - Condition 17 (3rd H.O.)

Figures 72, 73 and 74 show the actuator deviations occurring with a positive hardover (10 volt) input applied sequentially to channels 1, 2 and 3 with the system biased to a 50% extend position. Figure 72 shows the deviation occurring with a positive hardover input applied to channel 1. The actuator deviation is .40% of the full scale actuator stroke. The null offset after the failure is detected and channel 1 depressurized is .10% of the total actuator total stroke. The failure transient occurring with the second hardover input into channel 2 is approximately the same as that for the first hardover input. The deviation is .50% of the full scale actuator stroke and the null offset after depressurization of channel 2 is .2% of the total actuator stroke. The failure deviation for the third failure into channel three is 1.0% of the total actuator stroke. The failure logic arbitrarily depressurizes channel 3 after a .85 second time delay, allowing the actuator output to approach the original null position.

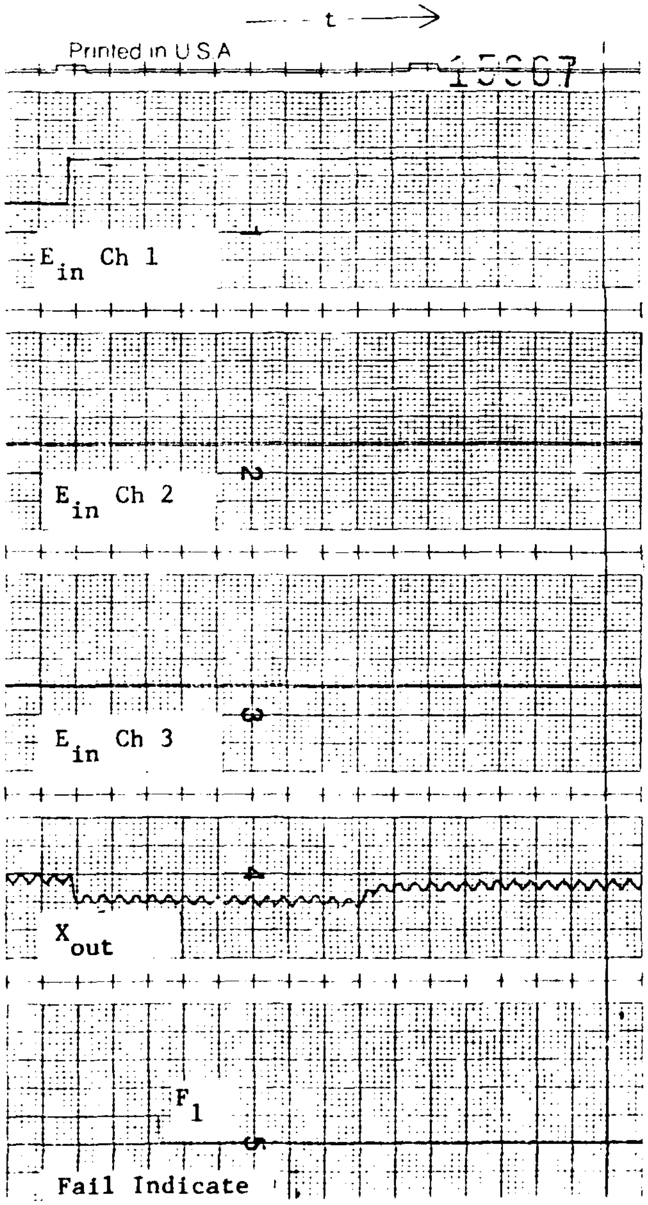
Figures 75, 76 and 77 show the actuator deviations occurring for negative hardover (-10 volt) inputs applied sequentially to channels 1, 2 and 3 with the system biased to 50% extend position. The deviation for a negative hardover input into channel 1 is shown on Figure 75 and is .70% of the total actuator stroke. The null offset after failure detection and depressurization of channel 1 is .20% of the total actuator stroke. The deviation for the second hardover input is shown on Figure 76 and was .60% of the total actuator stroke with a null offset of .20% of the total actuator stroke. As shown on Figure 77, the deviation with a third negative hardover input applied to channel 3 was 1.10% of the full scale actuator output.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 5/30/79

TEST - Failure Transiets - Condition 18 (1st H.O.)




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.0013 in/div
$t$ = 50 div/sec

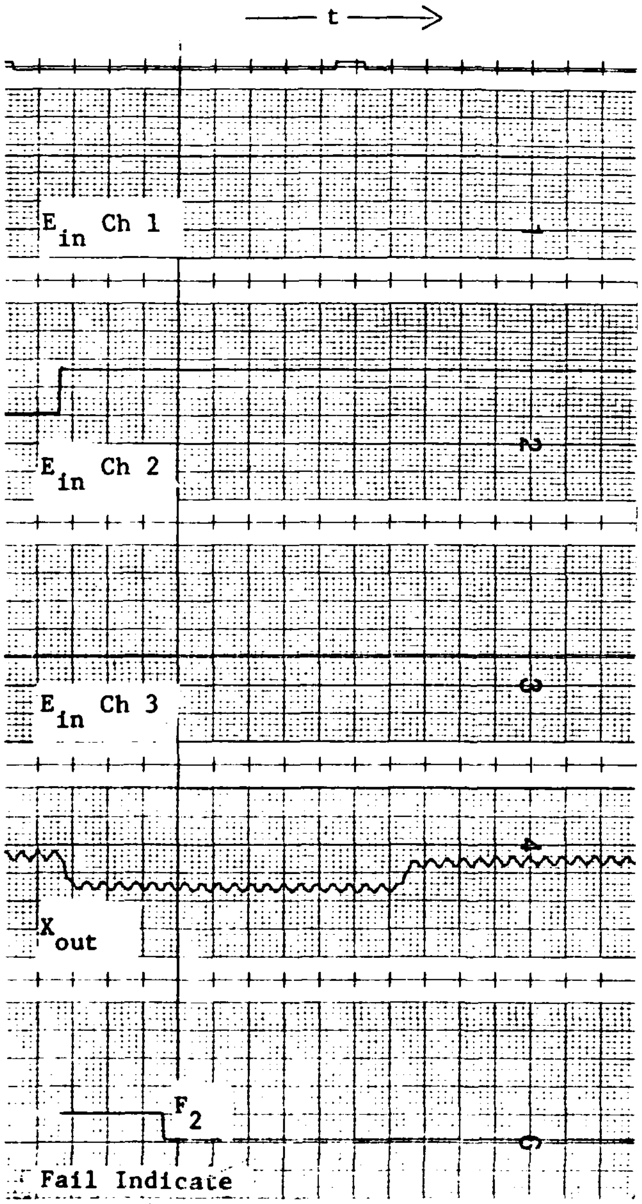
FIGURE 72 Failure Transients - Condition 18 (1st H.O.)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 5/30/79

TEST - Failure Transients - Condition 18 (2nd H.O.)




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.0013 in/div
t = 50 div/sec

FIGURE 73 Failure Transients - Condition 18 (2nd H.O.)

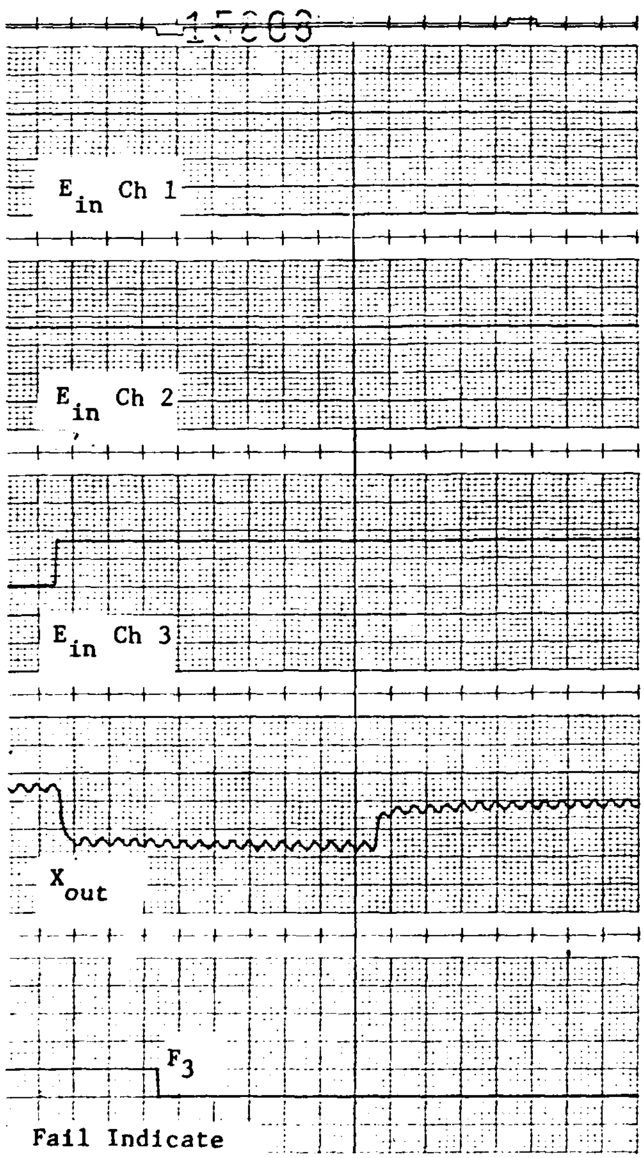
DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 5/30/79

TEST - Failure Transients - Condition 18 (3rd H.O.)

——— t ———>




Scale:
- $E_{in}$ = 1.000 v/div
- $X_{out}$ = 0.0013 in/div
- t = 50 div/sec

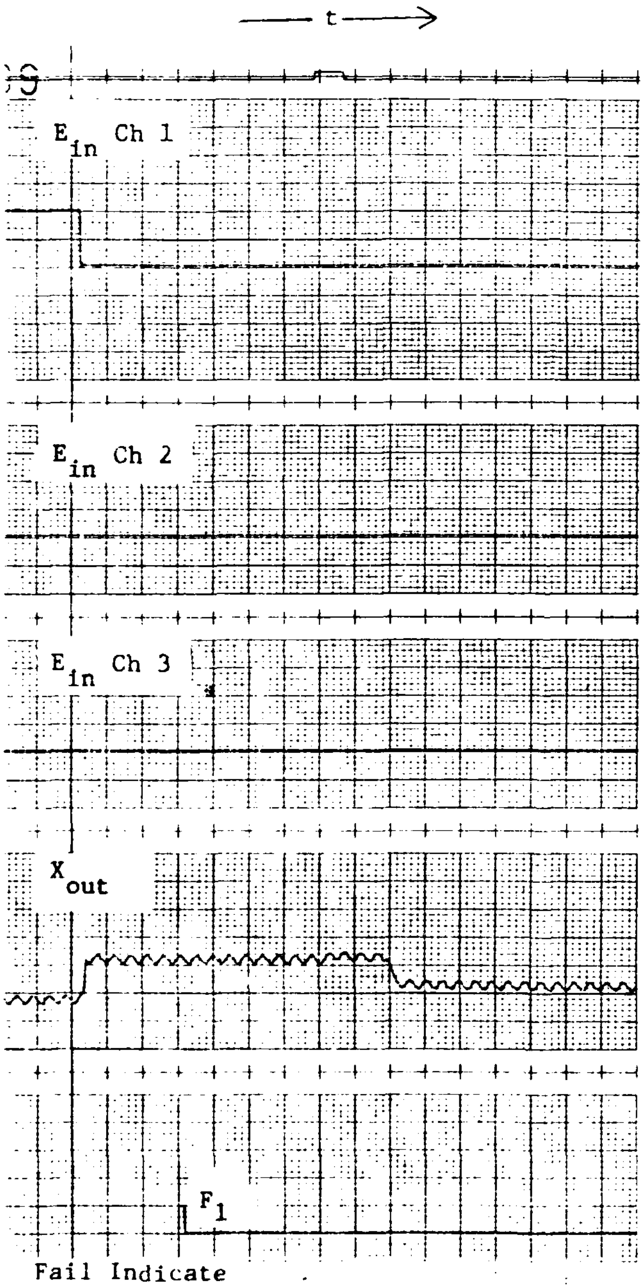
FIGURE 74 Failure Transients - Condition 18 (3rd H.O.)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 5/30/79

TEST - Failure Transients - Condition 19 (1st H.O.)




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.0013 in/div
t = 50 div/sec

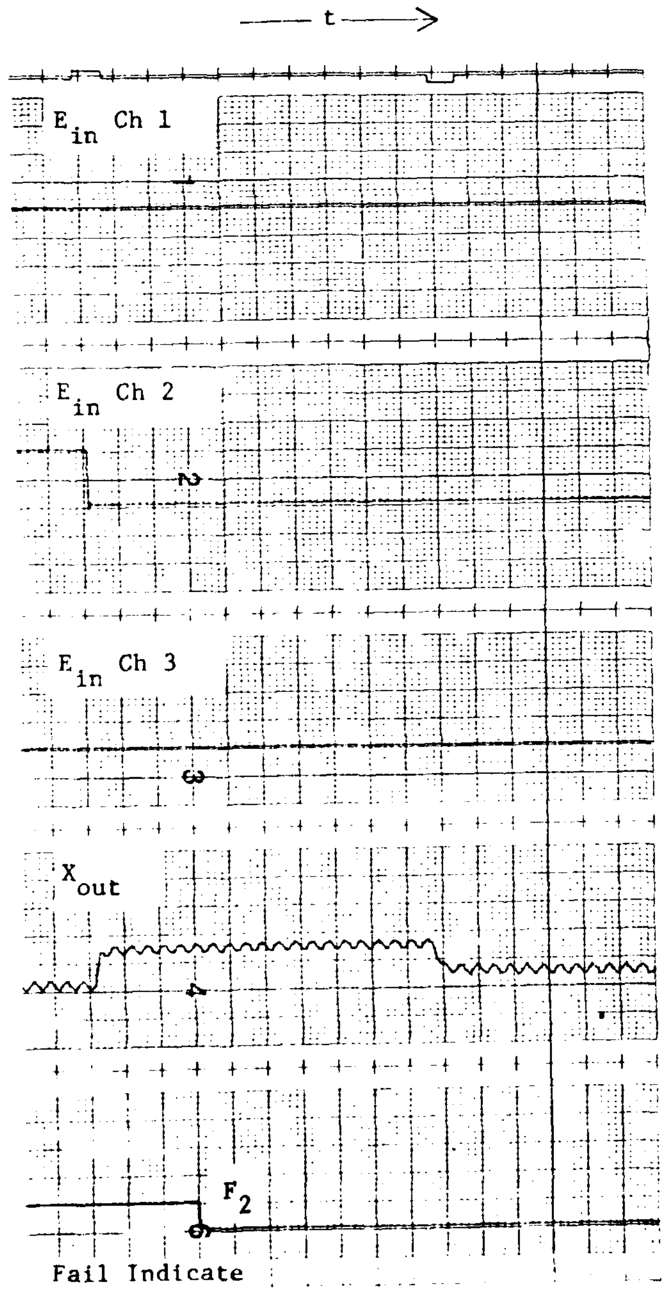
FIGURE 75 Failure Transients - Condition 19 (1st H.O.)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date Prepared 5/30/79

TEST - Failure Transients _ Condition 19 (2nd H.O.)




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.0013 in/div
t = 50 div/sec

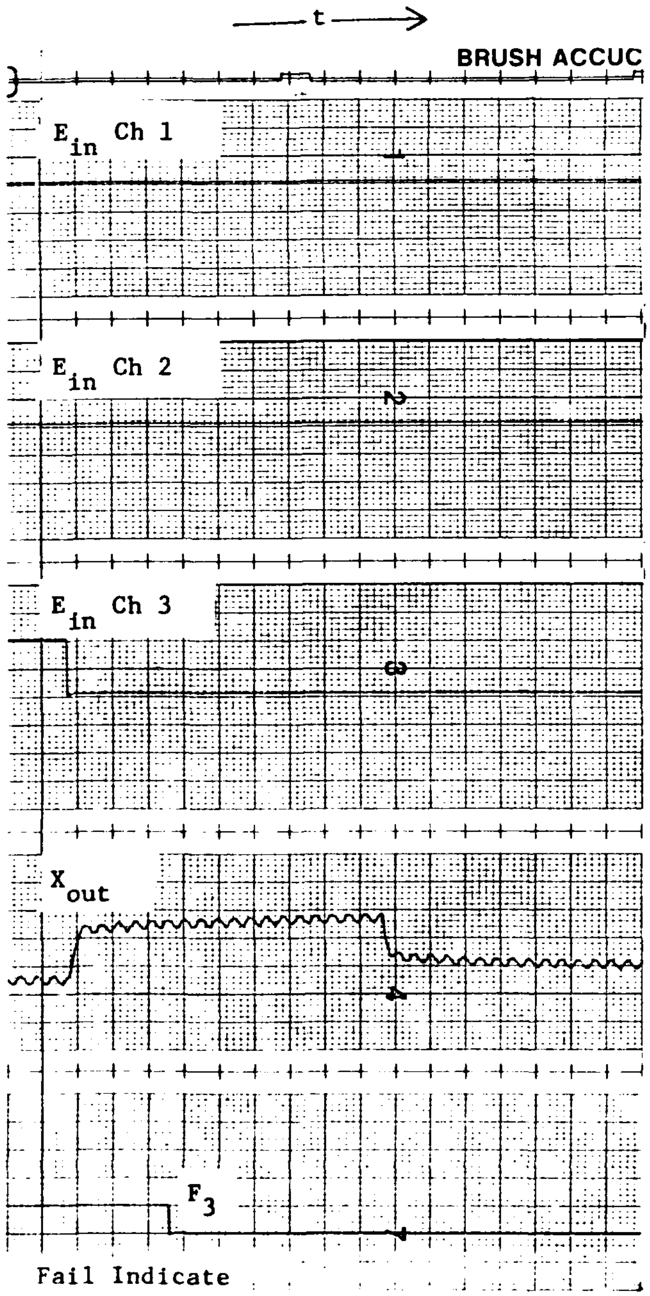
FIGURE 76 Failure Transients - Condition 19 (2nd H.O.)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 5/30/79

TEST - Failure Transients - Condition 19 (3rd H.O.)




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.0013 in/div
t = 50 div/sec

FIGURE 77 Failure Transients - Condition 19 (3rd H.O.)

Figures 78, 79 and 80 show the actuator deviations occurring for positive hardover inputs (+10 volt) applied sequentially to channels 1, 2 and 3 with the system biased to a 50% retract position. The deviation for the hardover input into channel 1 is .79% of the total actuator stroke. The null offset after failure detection and depressurization of channel 1 is .20% of the total actuator stroke. The actuator deviation for a second hardover input into channel 2 is .20% of the total actuator stroke. The null offset after depressurization is .30% of the total actuator stroke. The deviation for the 3rd failure input into channel 3 is .40% of the total actuator stroke.

Figures 81, 82 and 83 show the actuator deviations occurring for negative hardover inputs (-10 volt) applied sequentially to channels 1, 2 and 3 with the system biased to a 50% retract position. The deviation for the first failure is .70% of the total actuator stroke while the null offset after depressurization of channel 1 is .30% of the total actuator stroke. A second failure input into channel 2 produces an output deviation of 1.2% of the total actuator stroke and a null offset (after channel 2 is depressurized) of .40% of the total actuator stroke. The third failure into channel 3 produces an output deviation of 2.0% of the total actuator stroke.

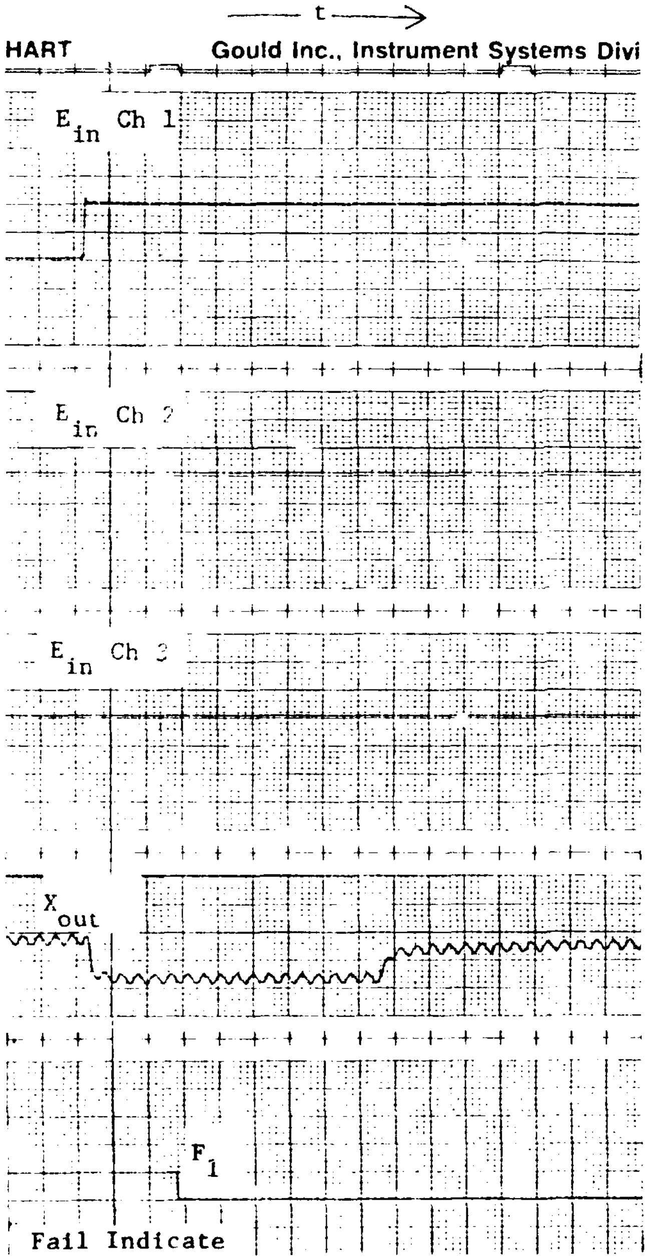
The actuator deviations for the positive hardovers are less for the second and third failures than those resulting from the negative hardover inputs. Note that the actual input hardover for negative hardovers is - 7 volts, since -3 volts is used to establish the initial bias position.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 5/30/79

TEST - Failure Transients - Condition 20 (1st H.O.)




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.0013 in/div
t = 50 div/sec

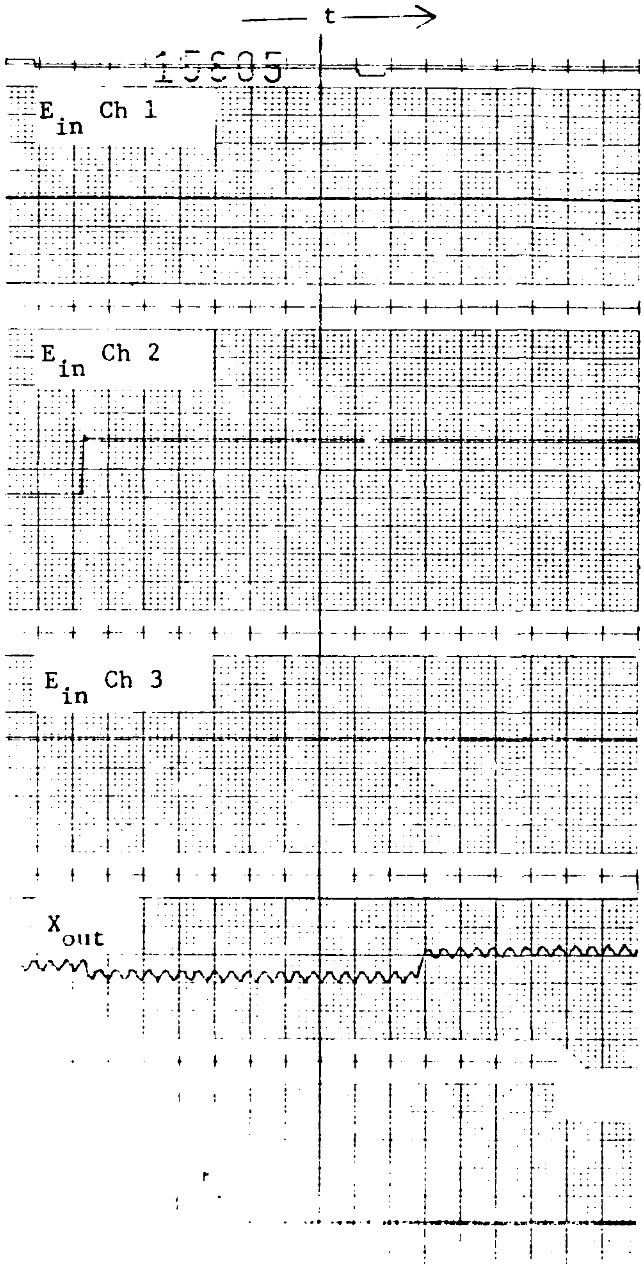
FIGURE 78 Failure Transients - Condition 20 (1st H.O.)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 5/30/79

TEST - Failure Transients - Condition 20 (2nd H.O.)




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.0013 in/div
t = 50 div/sec

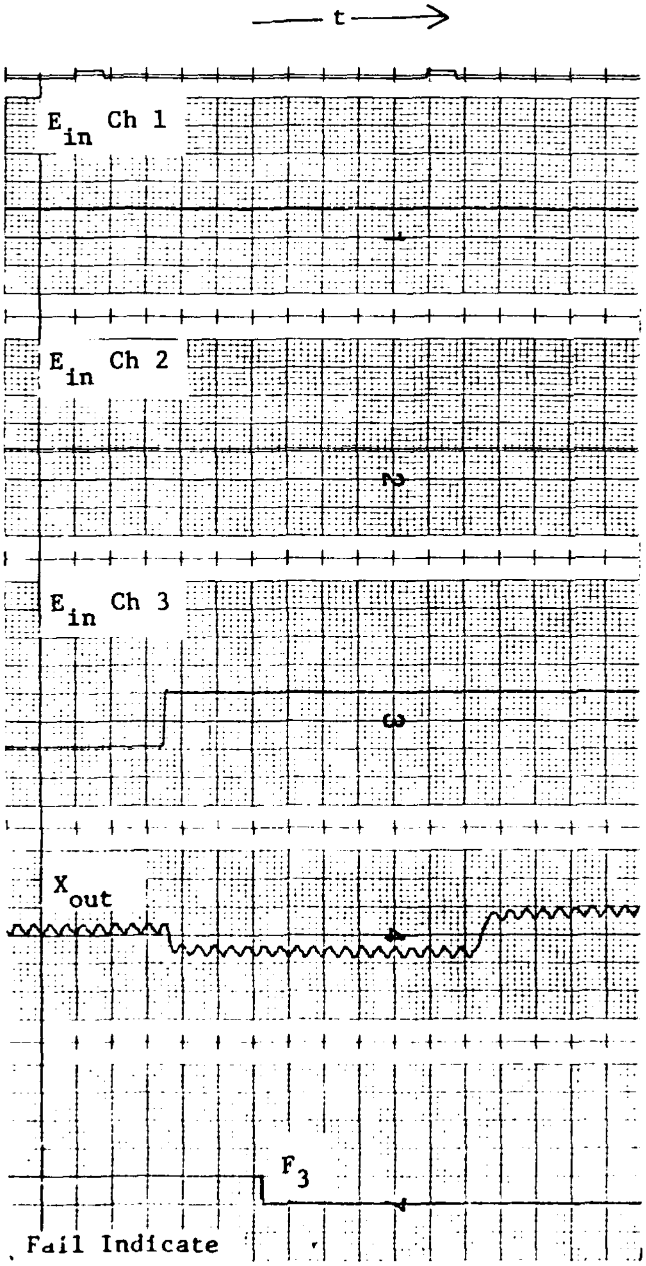
... Transients - Condition 20 (2nd H.O.)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date Prepared 5/30/79

TEST - Failure Transients - Condition 20 (3rd H.O.)




Scale: $E_{in}$ = 1.00 v/div
$X_{out}$ = 0.0013 in/div
t = 50 div/sec

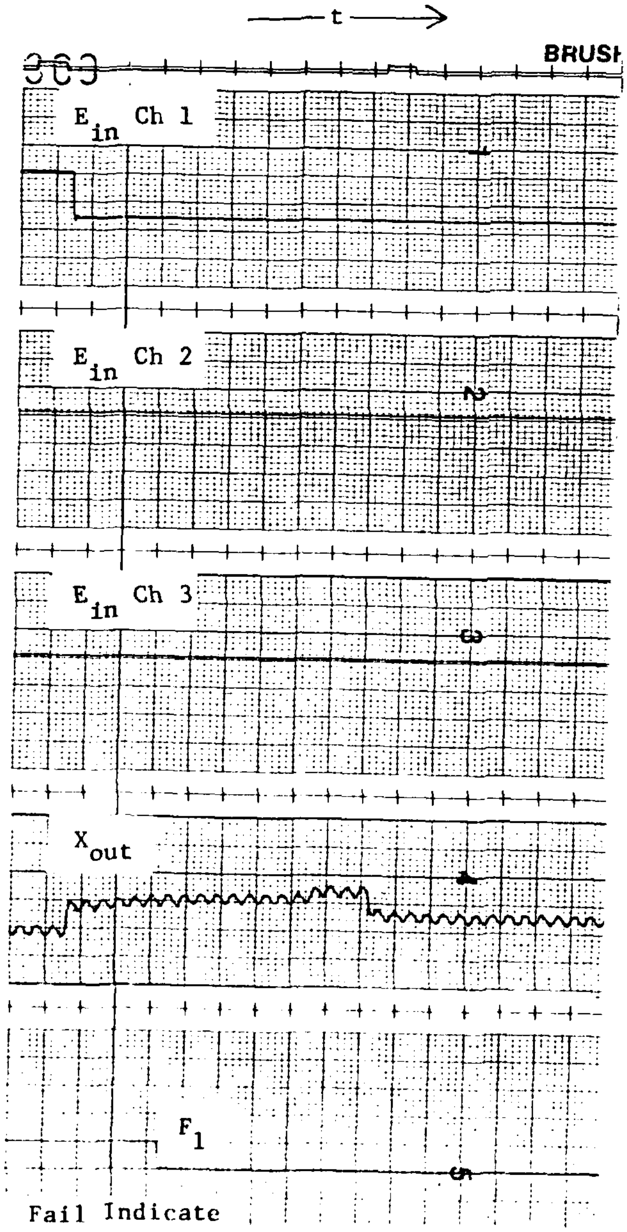
FIGURE 80 Failure Transients - Condition 20 (3rd H.O.)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 5/29/79

TEST - Failure Transients - Condition 21 (1st H.O.)




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.0013 in/div
t = 50 div/sec

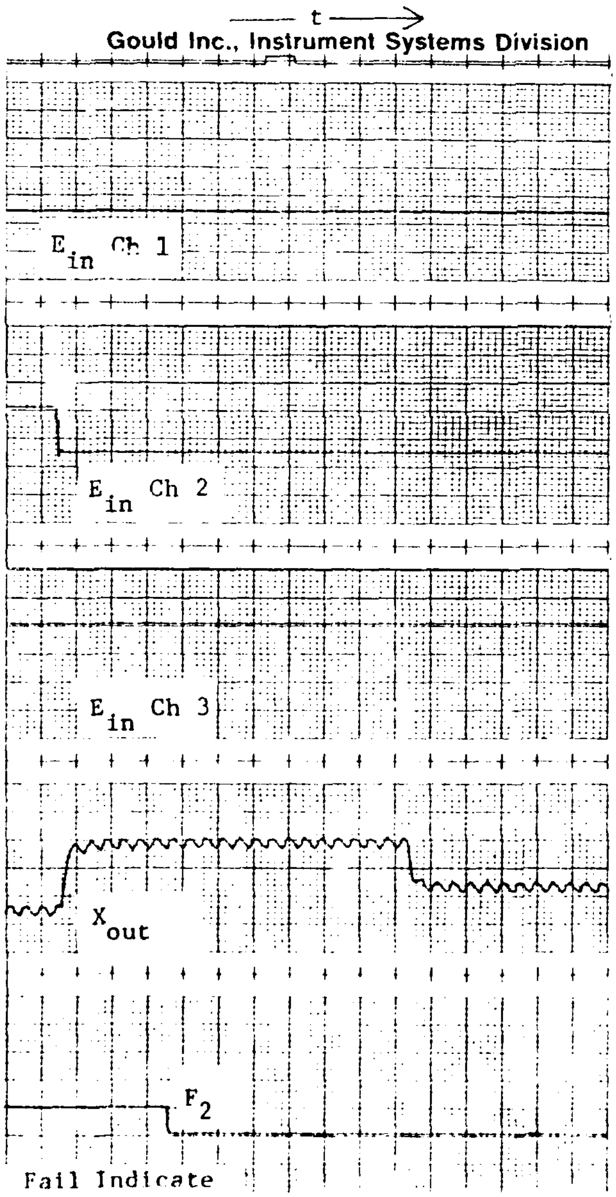
FIGURE 81 Failure Transients - Condition 21 (1st H.O.)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 5/29/79

TEST - Failure Transients - Condition 21 (2nd H.O.)




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.0013 in/div
t = 50 div/sec

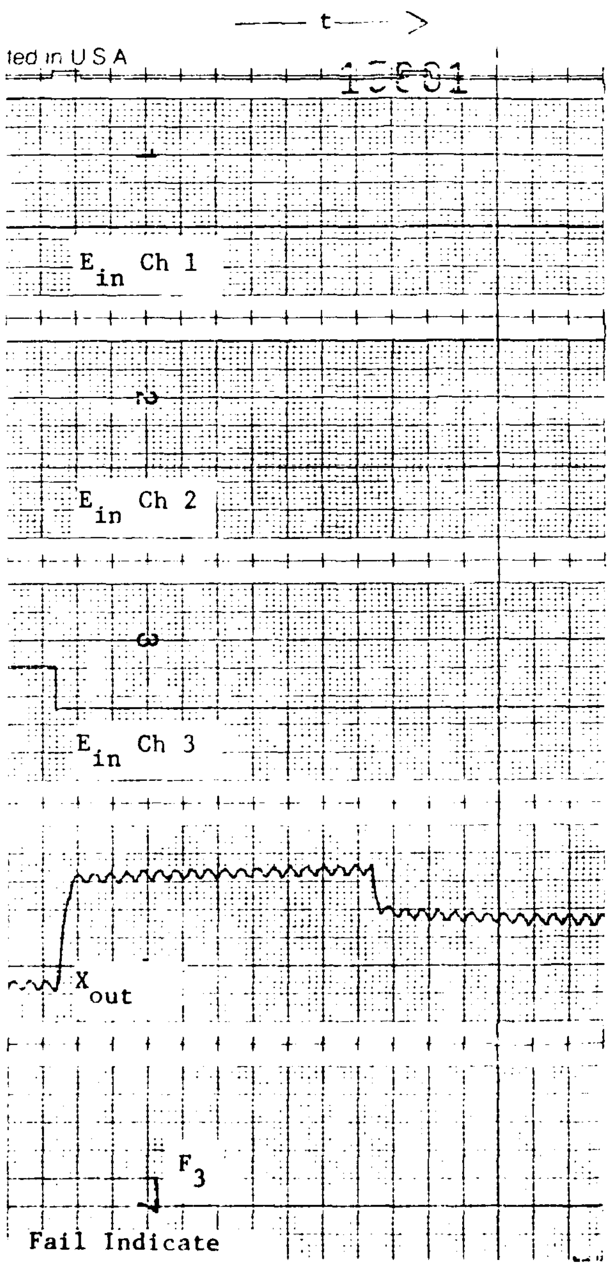
FIGURE 82 Failure Transients - Condition 21 (2nd H.O.)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 5/29/79

TEST - Failure Transients - Condition 21 (3rd H.O.)




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.0013 in/div
t = 50 div/sec

FIGURE 83 Failure Transients - Condition 21 (3rd H.O.)

Figures 84, 85 and 86 show the output change resulting from a hardover input applied sequentially to the input channels of the system while the actuator is cycling at approximately 10 Hz with an input amplitude just below that causing rate saturation. Figure 84 shows the output change resulting from a positive hardover input applied to channel 1. The effect of the input failure is a reduction in the peak amplitude of the actuator output in one direction of motion of 18% of the output signal. The second input failure as shown in Figure 85 causes a null shift of .25% of the maximum actuator stroke with no amplitude attenuation. The third failure input shown in Figure 86 shows the output amplitude attenuating to zero amplitude.

Figures 87, 88 and 89 show the actuator output change resulting from a negative hardover input applied sequentially to the channel inputs of the system while the actuator is cycling at approximately 10 Hz with an input amplitude just below that causing rate saturation. The results are similar to those with a positive hardover input. The first failure shown on Figure 87 causes an output attenuation in one direction of motion of 13% of the output signal. The second input failure shown on Figure 88 causes a null shift of .25% of the maximum actuator stroke. The effect of the third negative hardover input is to cause the actuator to stop responding to the sinusoidal input. The actuator does not go hardover, since channel 4 prevents channel 3 from driving the actuator output hardover.

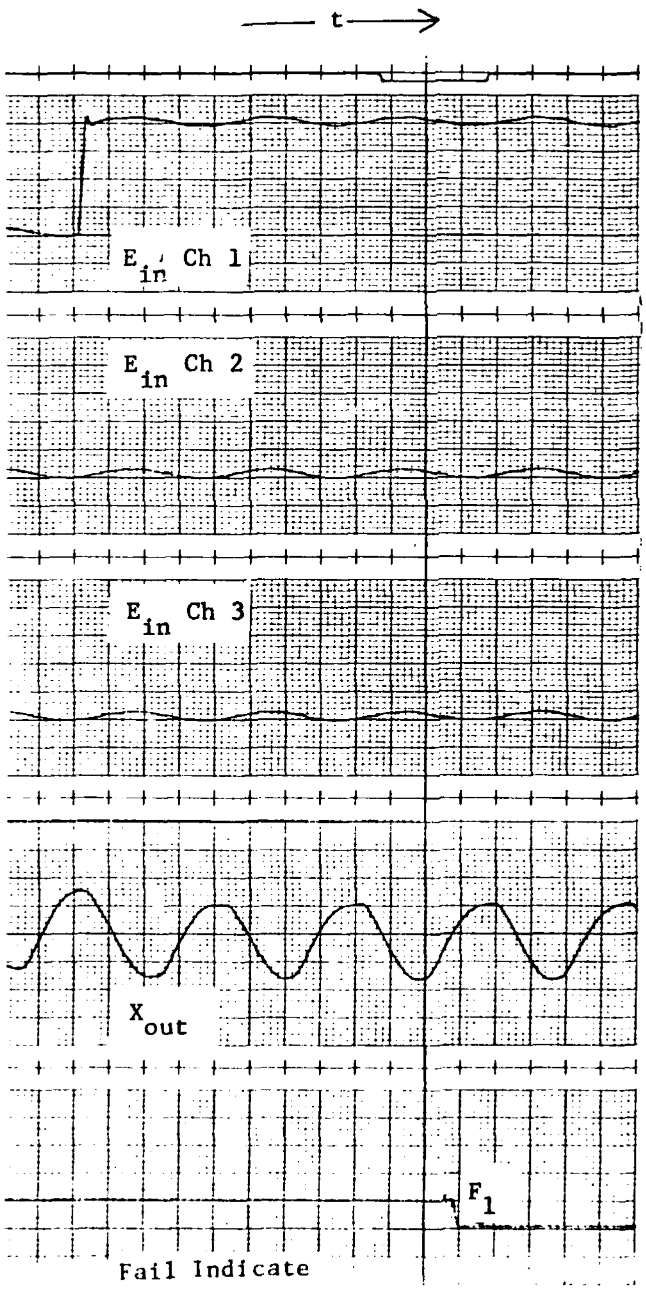
These results are similar to those obtained for the same test conditions and Configuration A. The pressure equalization feedback has no or little effect on the failure detection and actuator deviations for the hardover inputs under cycling conditions.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 6/4/79

TEST - Failure Transients - Condition 22 (1st H.O.)




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.0033 in/div
t = 200 div/sec

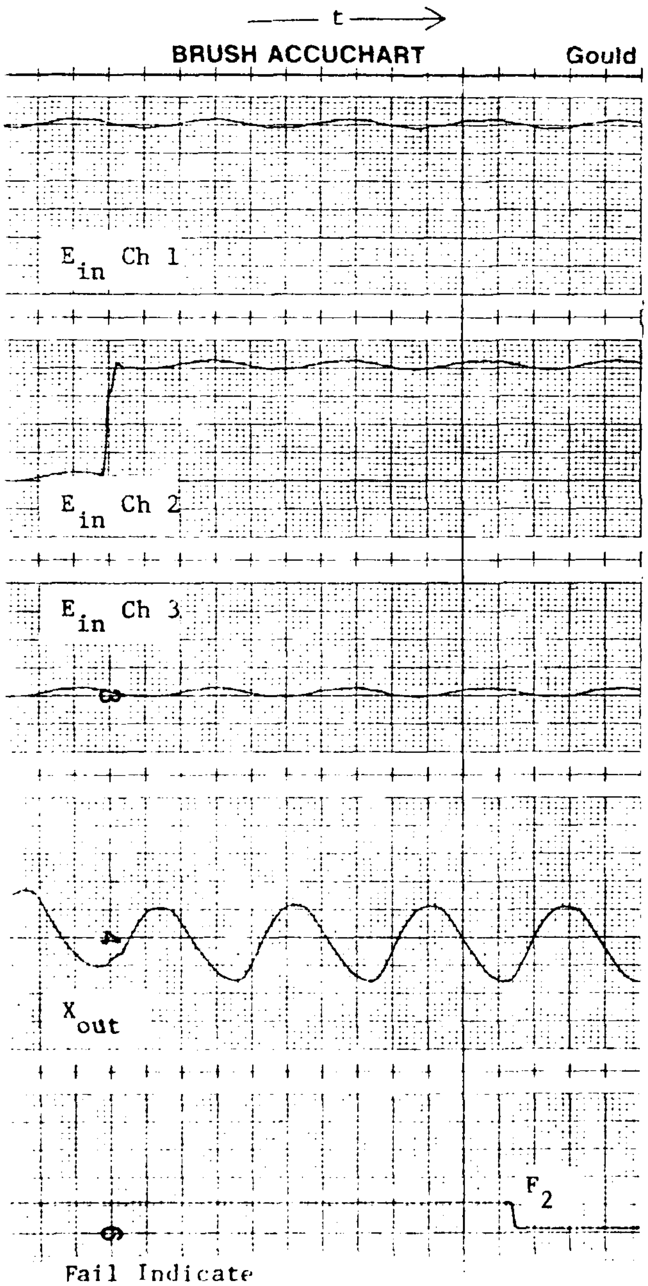
FIGURE 84 Failure Transients - Condition 22 (1st H.O.)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 6/4/79

TEST - Failure Transients - Condition 22 (2nd H.O.)




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.0033 in/div
t = 200 div/sec

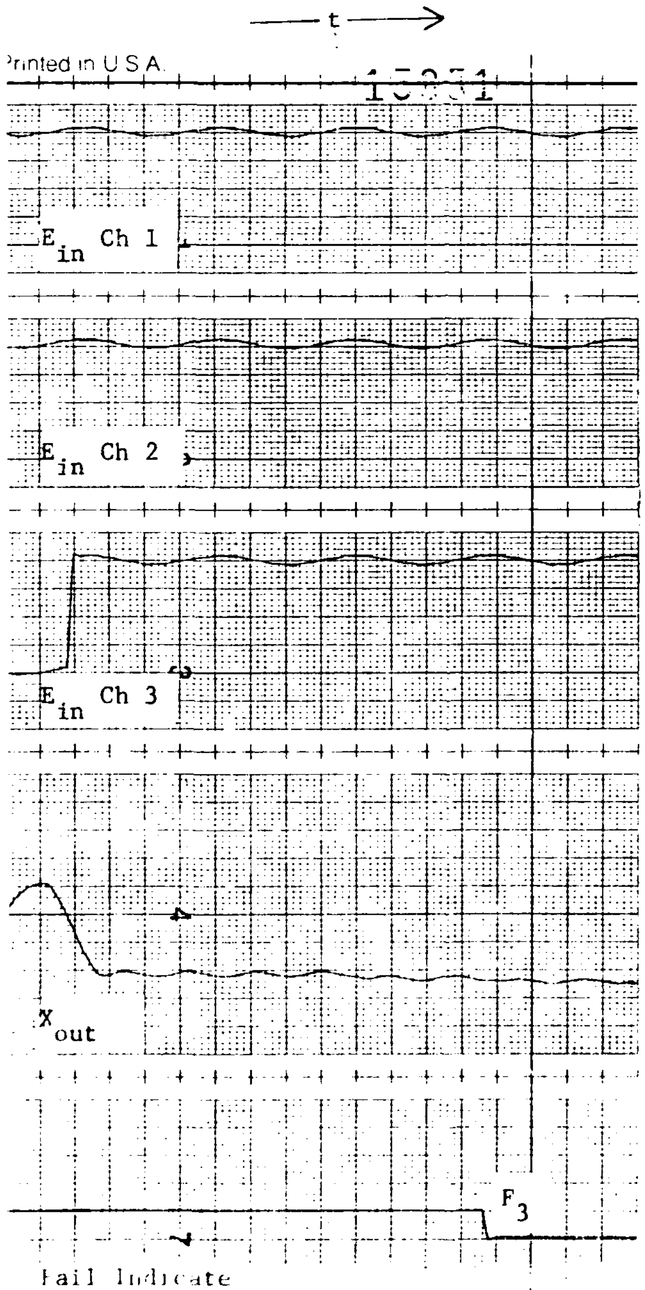
FIGURE 85 Failure Transients - Condition 22 (2nd H.O.)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 6/4/79

TEST - Failure Transients - Condition 22 (3rd H.O.)




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.0033 in/div
t = 200 div/sec

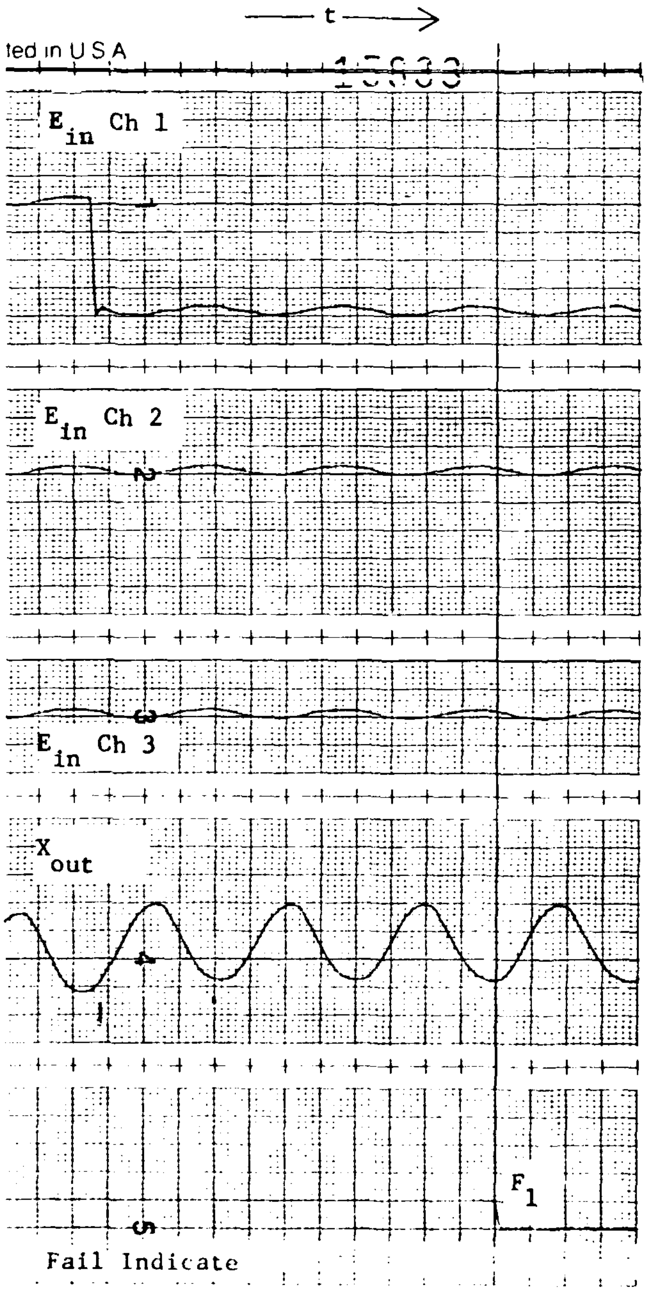
FIGURE 86 Failure Transients - Condition 22 (3rd H.O.)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date Prepared 6/4/79

TEST - Failure Transients - Condition 23 (1st H.O.)




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.0033 in/div
t = 200 div/sec

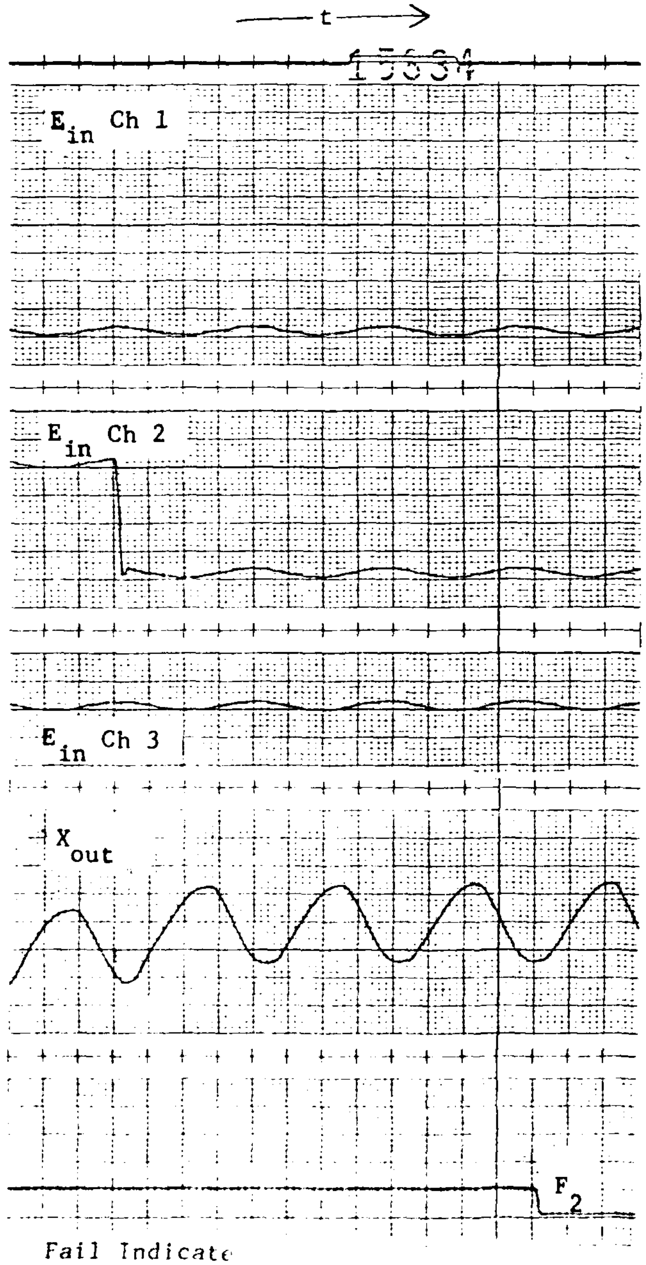
FIGURE 87 Failure Transients - Condition 23 (1st H.O.)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date Prepared 6/4/79

TEST - Failure Transients - Condition 23 (2nd H.O.)




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.0033 in/div
t = 200 div/sec

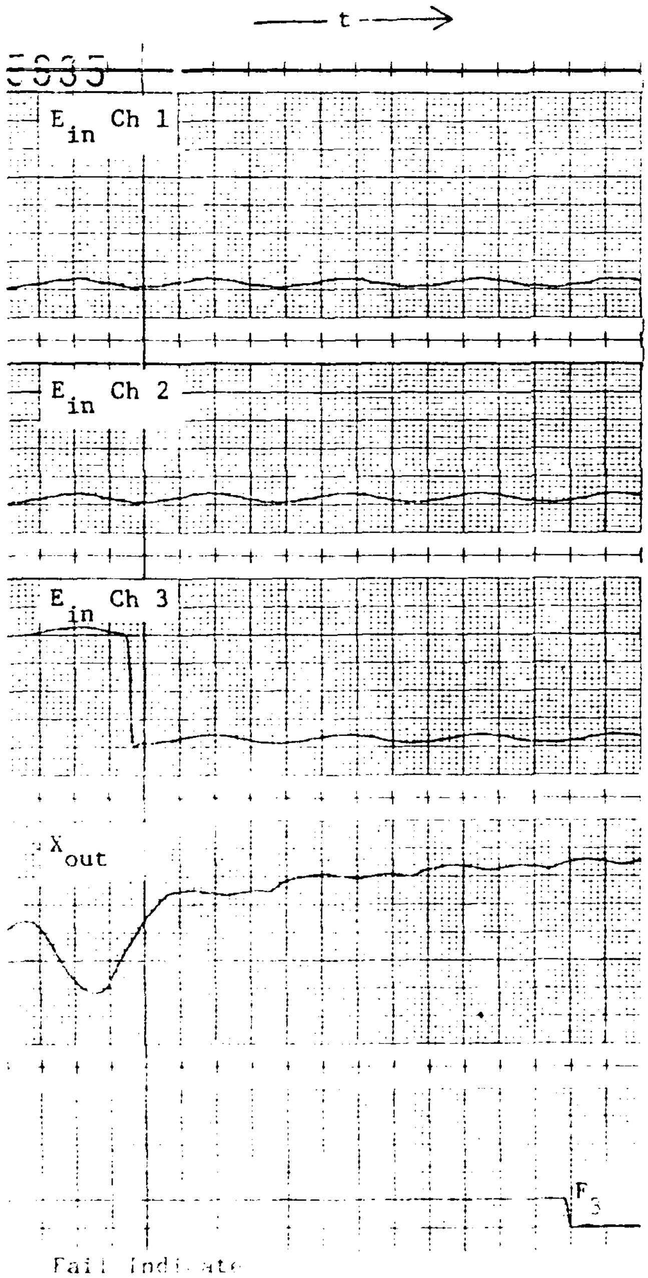
FIGURE 88 Failure Transients - Condition 23 (2nd H.O.)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date Prepared 6/4/79

TEST - Failure Transients - Condition 23 (3rd H.O.)




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.0033 in/div
t = 200 div/sec

FIGURE 8[illegible] Failure Transients - Condition 23 (3rd H.O.)

### 3.7.3.3 Simultaneous Hardover Input Failure Transient

Figure 90 shows the effect of hardover inputs applied simultaneously to channels 1 and 2 with an initial bias input. For this condition, the failure logic does not vote a failure and the resulting motion of the actuator output is a hardover displacement of the actuator with a hardover position reached in 1.9 seconds after the hardover inputs. Since channel 4 is limited to a 50% force output until a failure is voted, the force level capability of channel 1 plus 2 is greater than the force level of channel 3 plus 4. This allows the simultaneous input failures to drive the actuator output hardover. Simultaneous failures for the system would be failures occurring within the logic voting time of .25 seconds. This bias input test was not conducted on Configuration A.

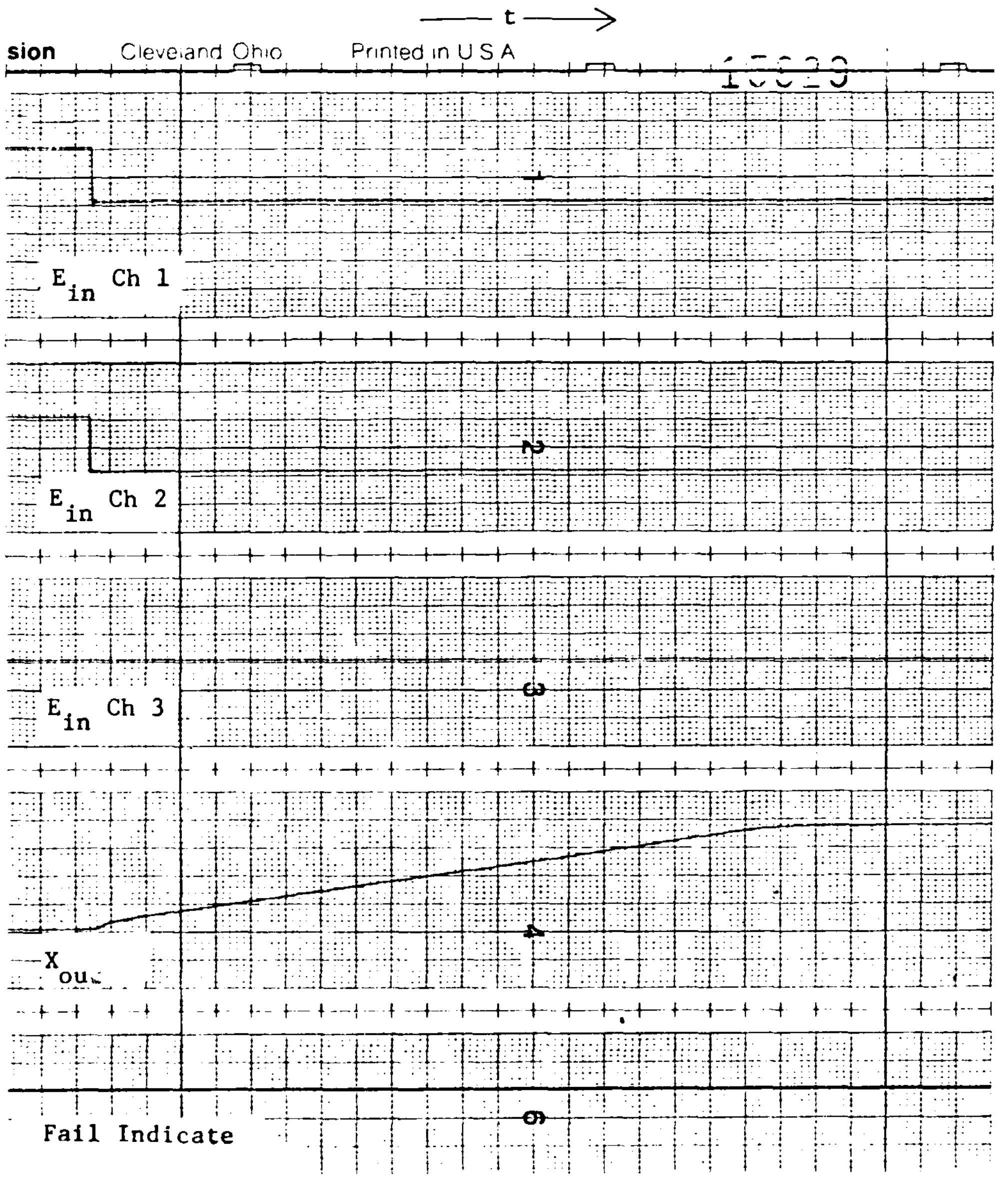
Figure 91 shows the effect of hardover inputs applied simultaneously to channels 1 and 2 with the system initially subjected to a null (0 voltage) input command. The actuator deviates to a new position 4.7% of the total actuator stroke away from the initial position. The actuator does not travel hardover, as was the case with the initial bias input condition of Figure 90. The reason for this is that the test condition causes a failure to be voted long enough to increase channel 4's force limit to 100% but not long enough to cause depressurization of channel 3. The actuator moves only far enough to cause channel 1 and 2 to be totally opposed by channels 3 and 4. For Figure 90, the bias input prevented any failure voting from occurring. The test results shown on Figure 91 are similar to those obtained with Configuration A. However, the actuator movement to obtain force cancellation increased from 1.95% to 4.7% of the total actuator stroke. This is a result of the pressure equalization feedback

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 5/31/79

TEST - Failure Transients - Condition 24




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.033 in/div
t = 50 div/sec

FIGURE 90 Failure Transients - Condition 24

AD-A091 559 DYNAMIC CONTROLS INC DAYTON OHIO F/G 1/3
RESEARCH AND DEVELOPMENT OF CONTROL ACTUATION SYSTEMS FOR AIRCR--ETC(U)
JUL 80 G D JENNEY F33615-77-C-3077

UNCLASSIFIED AFFDL-TR-79-3117-VOL-2 NL

3 OF 5

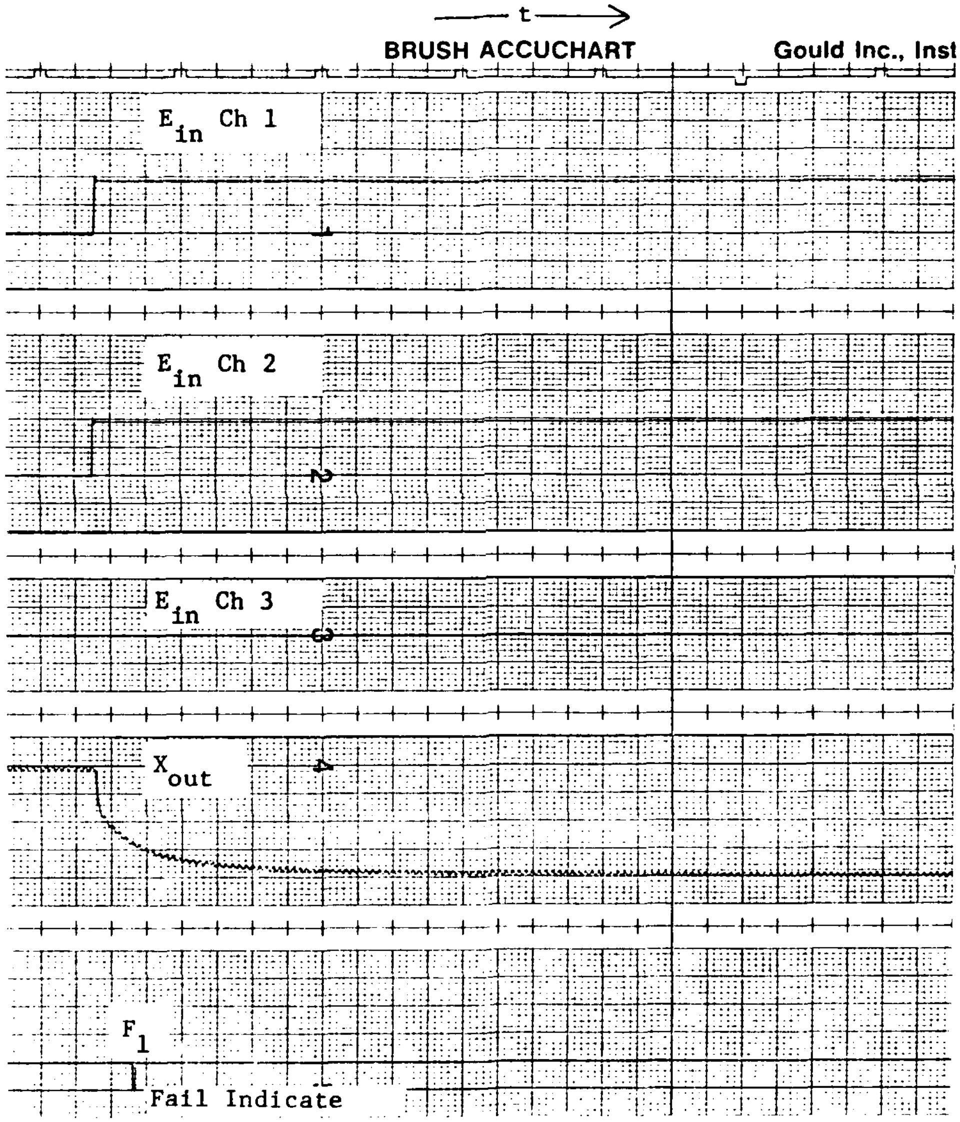
AD A091559

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 6/5/79

TEST - Failure Transients - Condition 26 (+H.O.)




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.0033 in/div
t = 20 div/sec

FIGURE 91 Failure Transients - Condition 26 (+H.O.)

circuit being connected for Configuration B. The negative pressure feedback requires that a larger error signal be developed for a given force output from a channel's actuator than when negative pressure feedback is not used.

Figure 92 shows the effect of simultaneous grounding of the inputs to channels 1 and 2 with the system operating at a frequency of .5 Hz with an input just below that which would cause rate saturation distortion. The effect of the applied input failures is to reduce the output of the actuator to less than 50% of the initial amplitude with distortion amplitude clipping. As shown on Figure 92, the failure logic votes failures for channels 3 and 4, but does not latch. From the change in actuator motion, it appears that channels 3 and 4 command output of the actuator only far enough to cause the grounded input channels to totally oppose their force output. The failure logic apparently does not vote failures long enough to depressurize either channel 3 or 4.

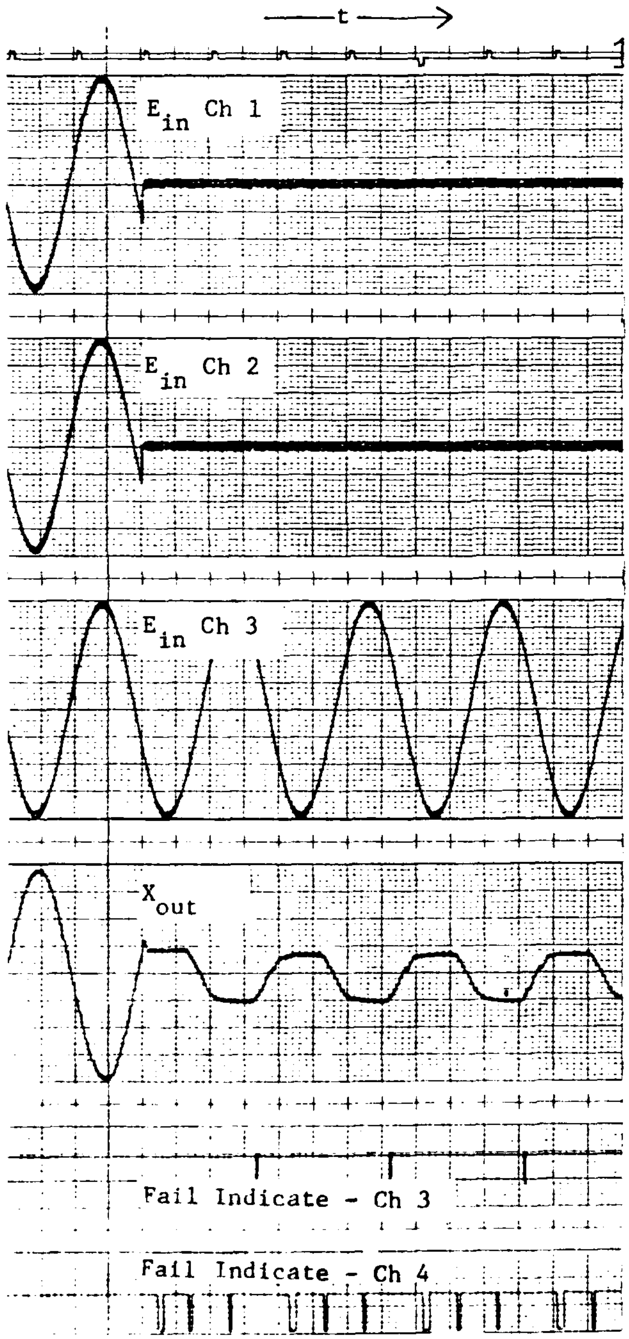
Figure 93 shows the effect of simultaneous hardover inputs into channels 1 and 2 with the system operating at 10 Hz with the maximum unsaturated input amplitude. The failure logic does vote a fourth channel failure indication briefly and the actuator output moves 7.5% of the total actuator stroke in 1.4 seconds and stops. The actuator output does not go hardover. This indicates that the channel 4 force limit has been increased to 100%, allowing channels 3 and 4 to cancel out the force outputs of channels 1 and 2. The actuator does not continue to respond to the 10 Hz input command after the hardover failure inputs. This result is similar to that obtained with Configuration A for the same test condition.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 6/5/79

TEST - Failure Transients - Condition 25




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.0033 in/div
t = 10 div/sec

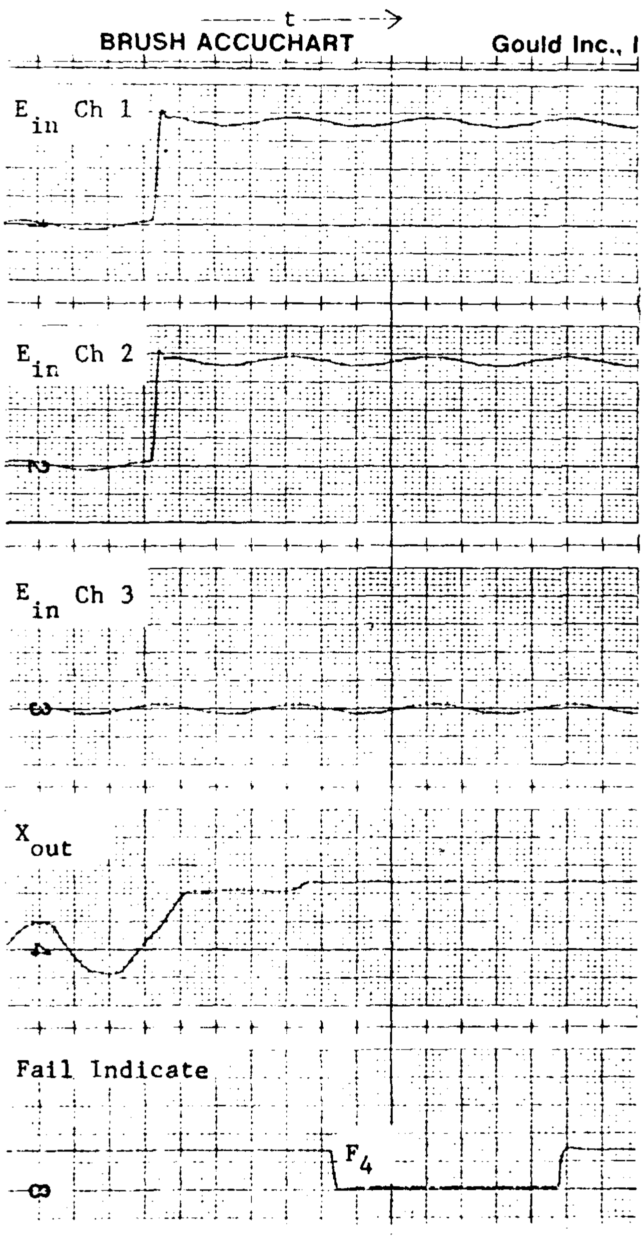
FIGURE 92 Failure Transients - Condition 25

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration A

Date
Prepared 5/24/79

TEST - Failure Transients - Condition 27




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.0033 in/div
t = 200 div/sec

FIGURE 93 Failure Transients - Condition 27

Figures 94 through 99 show the failure transients associated with a slowover input failure applied sequentially to channels 1, 2 and 3 for both extend and retract slowover inputs.

Figure 94 shows the effect of an extend slowover ramp of an amplitude varying from 0 to 1.0 volt at a rate of .4 volts/sec applied to the input of channel 1. The actuator initially responds to the input until the failure logic depressurizes channel 1 and changes the force limit of channel 4. The maximum actuator deviation from null is .37% of the maximum actuator stroke.

Figure 95 shows the effect of an extend slowover ramp of an amplitude varying from 0 to 1.0 volts at a rate of .4 volts/sec applied to channel 2 (after channel 1 has been depressurized and channel 4's force limit has been increased to 100%). The amplitude of the extend polarity ramp was apparently too small to cause the failure logic to vote a failure. The failure logic voted a failure on the retract polarity of the input ramp. The output deviation of the actuator is 34% of the total actuator stroke with the deviation after depressurization of channel 2 being a null offset of .13 of the total actuator stroke.

Figure 96 shows the effect of an extend slowover ramp of an amplitude varying from 0 to 1.0 volts at a rate of .4 volts/sec applied to channel 3 (after channel 1 and 2 have been depressurized). The output deviation is .8% of the total actuator stroke.

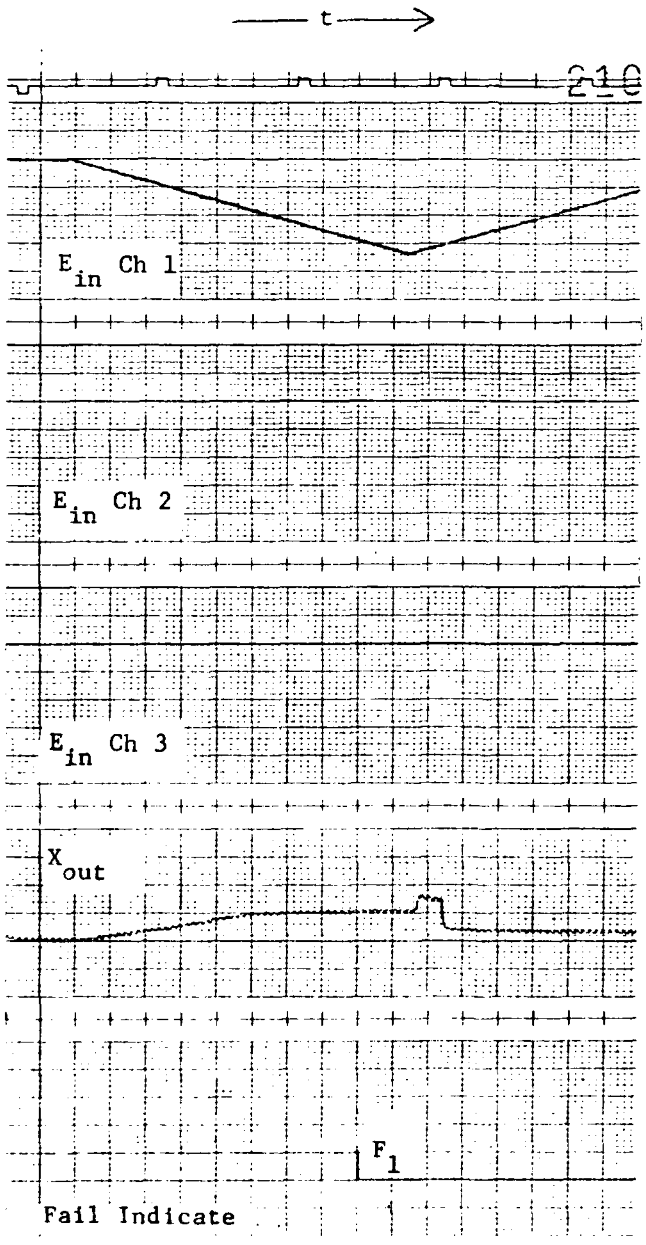
Figures 97, 98 and 99 show the deviations for retract slowover ramps applied sequentially to channels 1, 2 and 3 respectively. The test results are similar to those obtained for the extend slowover inputs.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date Prepared 6/1/79

TEST - Failure Transients - Condition 28 (1 Ch Extend)




Scale: $E_{in}$ = .05 v/div
$X_{out}$ = 0.0007 in/div
t = 20 div/sec

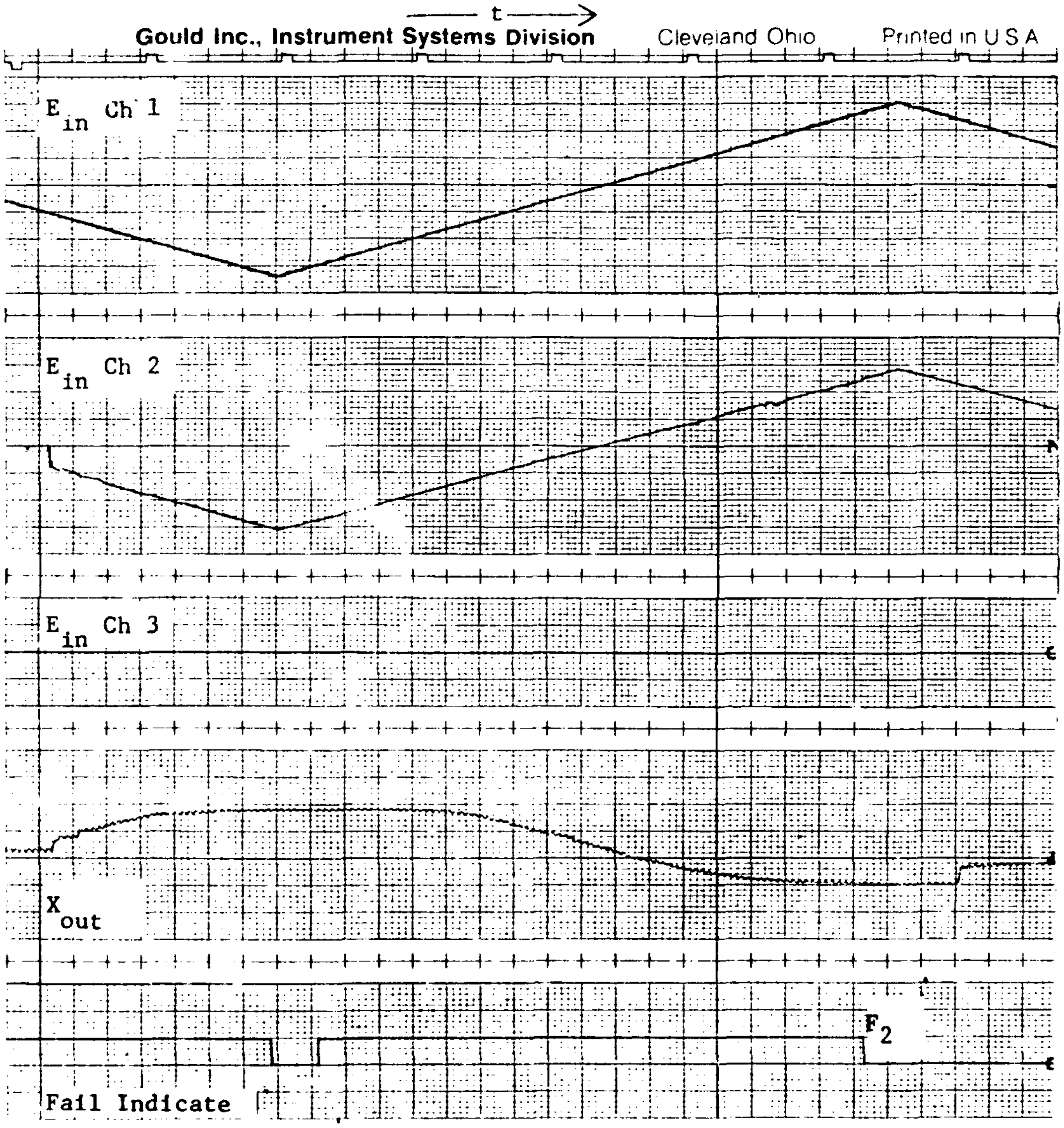
FIGURE 94 Failure Transients - Condition 28 (1 Ch Extend)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 6/1/79

TEST - Failure Transients - Condition 28 (2 Chs. Extend)




Scale: $E_{in}$ = .05 v/div
$X_{out}$ = 0.0007 in/div
t = 20 div/sec

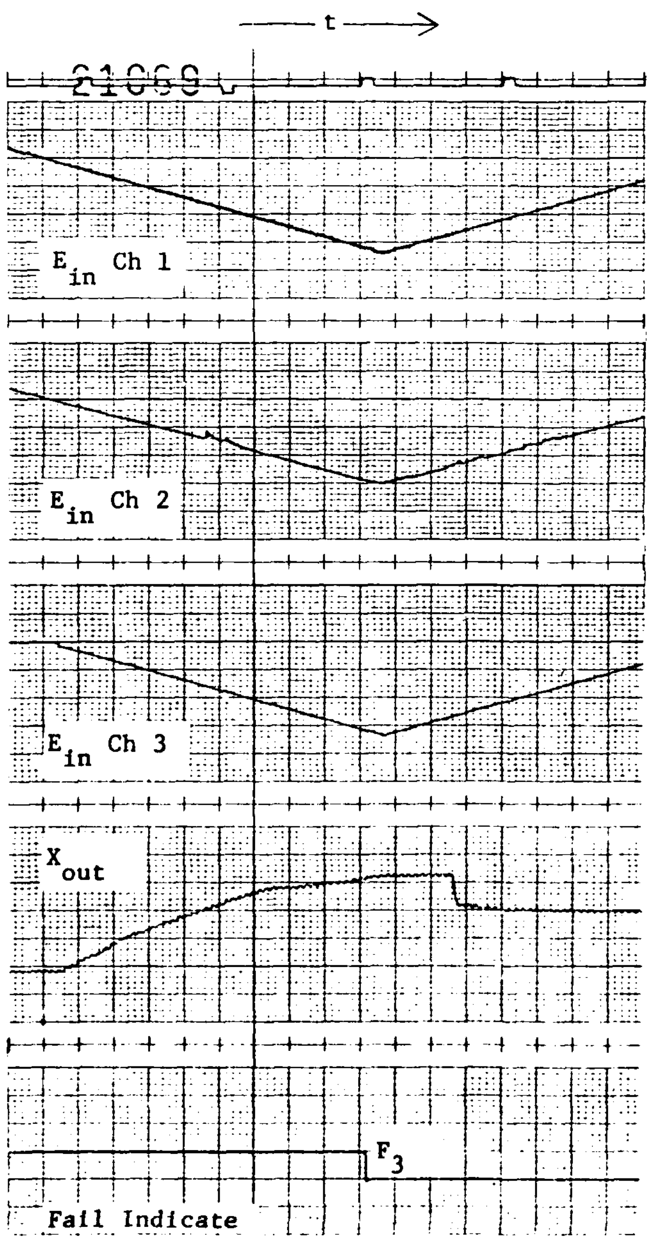
FIGURE 95 Failure Transients - Condition 28 (2 Chs. Extend)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 6/1/79

TEST - Failure Transients - Condition 28 (3 Chs. Extend)




Scale: $E_{in}$ = .05 v/div
$X_{out}$ = 0.0007 in/div
t = 20 div/sec

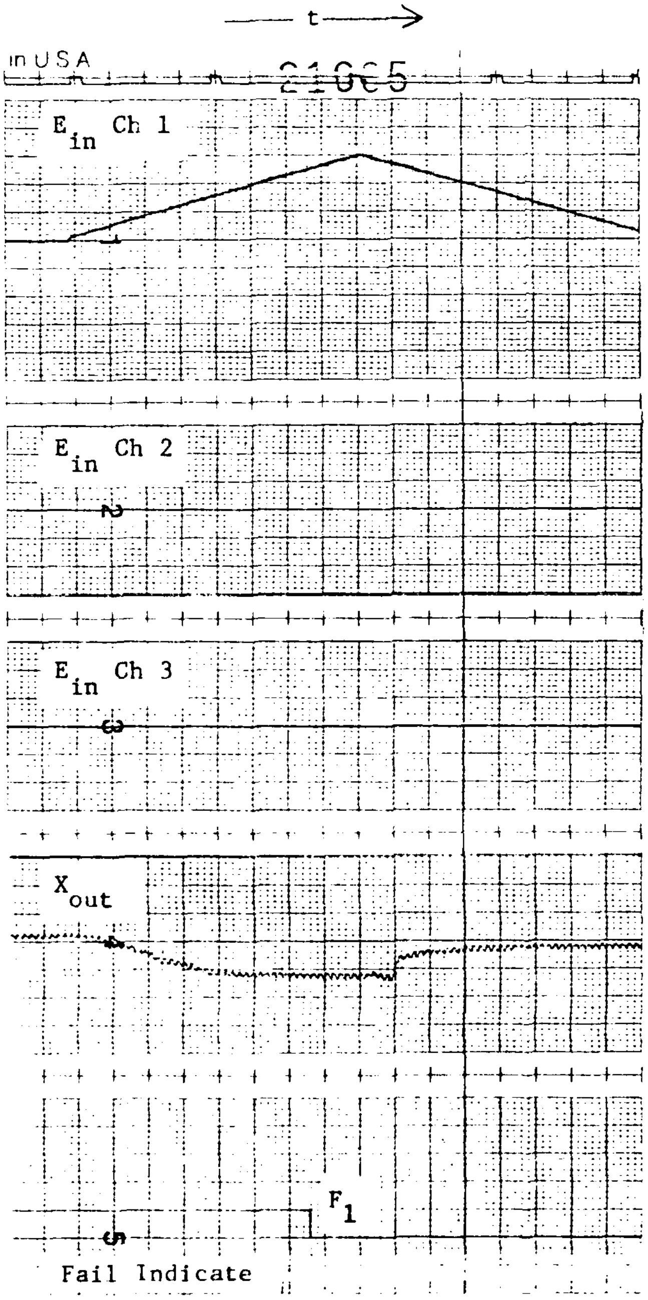
FIGURE 96 Failure Transients - Condition 28 (3 Chs. Extend)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 6/1/79

TEST - Failure Transients - Condition 28 (1 Ch Retract)




Scale: $E_{in}$ = .05 v/div
$X_{out}$ = 0.0007 in/div
t = 20 div/sec

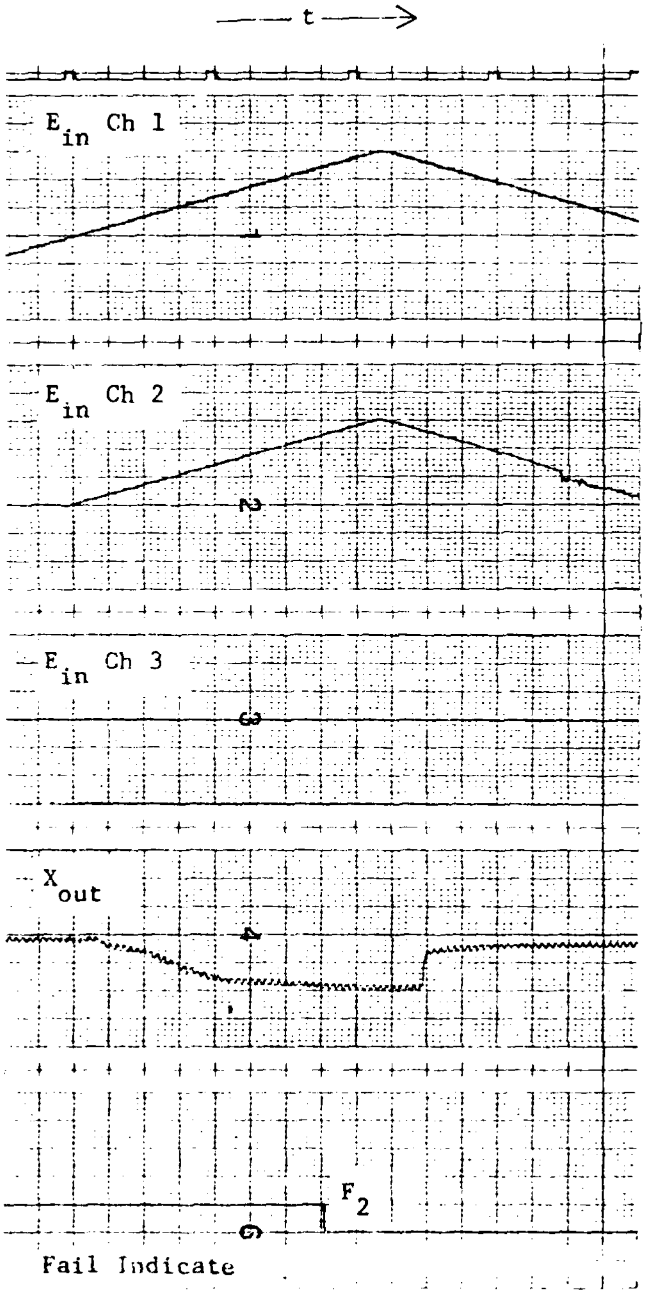
FIGURE 97 Failure Transients - Condition 28 (1 Ch Retract)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 6/1/79

TEST - Failure Transients - Condition 28 (2 Chs. Retract)




Scale: $E_{in}$ = .05 v/div
$X_{out}$ = 0.0007 in/div
t = 20 div/sec

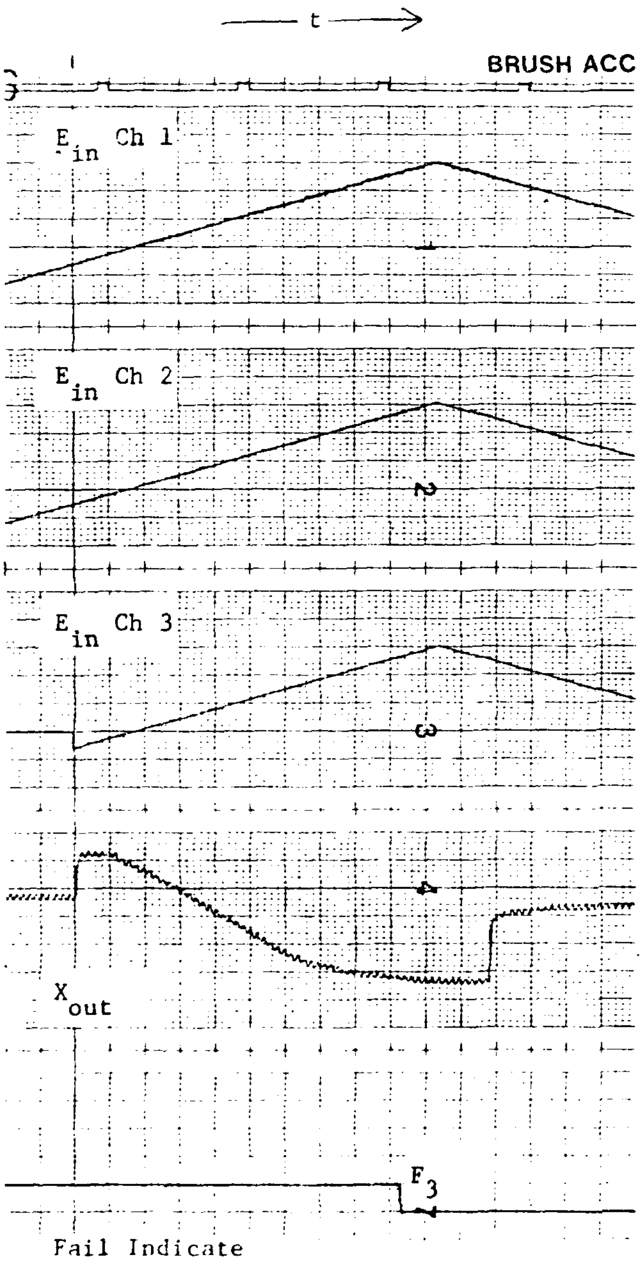
FIGURE 98 Failure Transients - Condition 28 (2 Chs. RetractO

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 6/1/79

TEST - Failure Transients - Condition 28 (3 Chs. Retract)




Scale: $E_{in}$ = .05 v/div
$X_{out}$ = 0.0007 in/div
t = 20 div/sec

FIGURE 99 Failure Transients - Condition 28 (3 Chs. Retract)

The slowover failure test results obtained for Configuration B are similar to those obtained for Configuration A. This indicates that the pressure equalization feedback does not noticably change the output deviations of the system for slowover failures.

This is consistent with the principle of the pressure feedback circuit not operating below a set design level. The actuator deviation required to cause the unfailed channels to offset the channel with a slowover input does not change with the application of pressure feedback equalization. This is because the differential pressures required from the unfailed channels for the force offset are not large enough to exceed the level for pressure feedback activation. The main effect of the pressure feedback on slowover input failures is to allow a larger input command difference before a failure is voted.

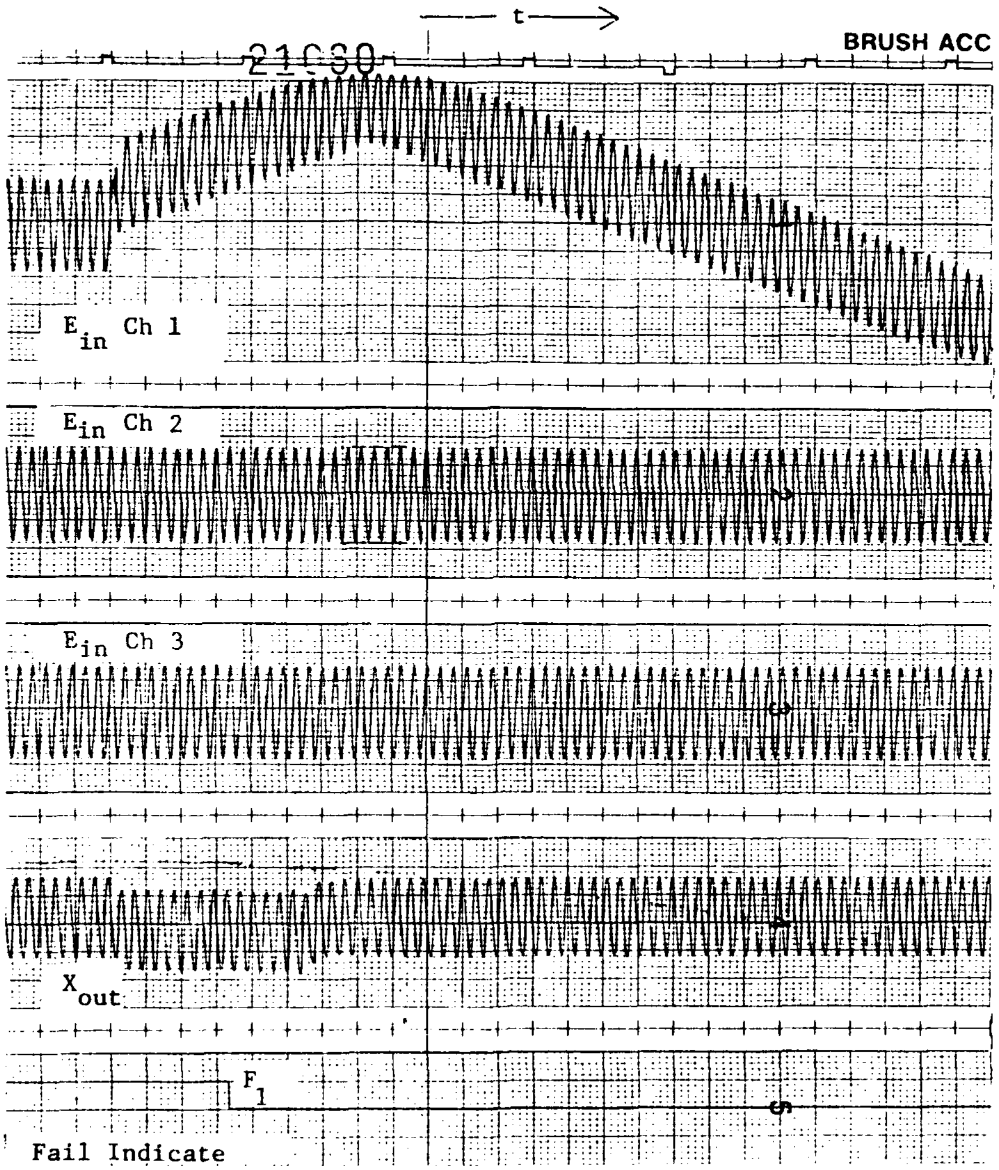
Figures 100, 101 and 102 show the effect of sequentially applying ramp inputs to channels 1, 2 and 3 while operating the system at 10 Hz at a maximum unsaturated amplitude. The failure ramp input is slow enough to be detected as a failure. The primary effect of the slowover inputs is a null shift until failure logic depressurizes the channel. The third ramp input failure was not detected by the failure logic and channel three was not depressurized. With the exception of the third channel failure, these results with Configuration B are similar to those obtained for Configuration A and this particular evaluation test.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 6/5/79

TEST - Failure Transients - Condition 29 (1 Chs. Retract)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.0033 in/div
t = 20 div/sec

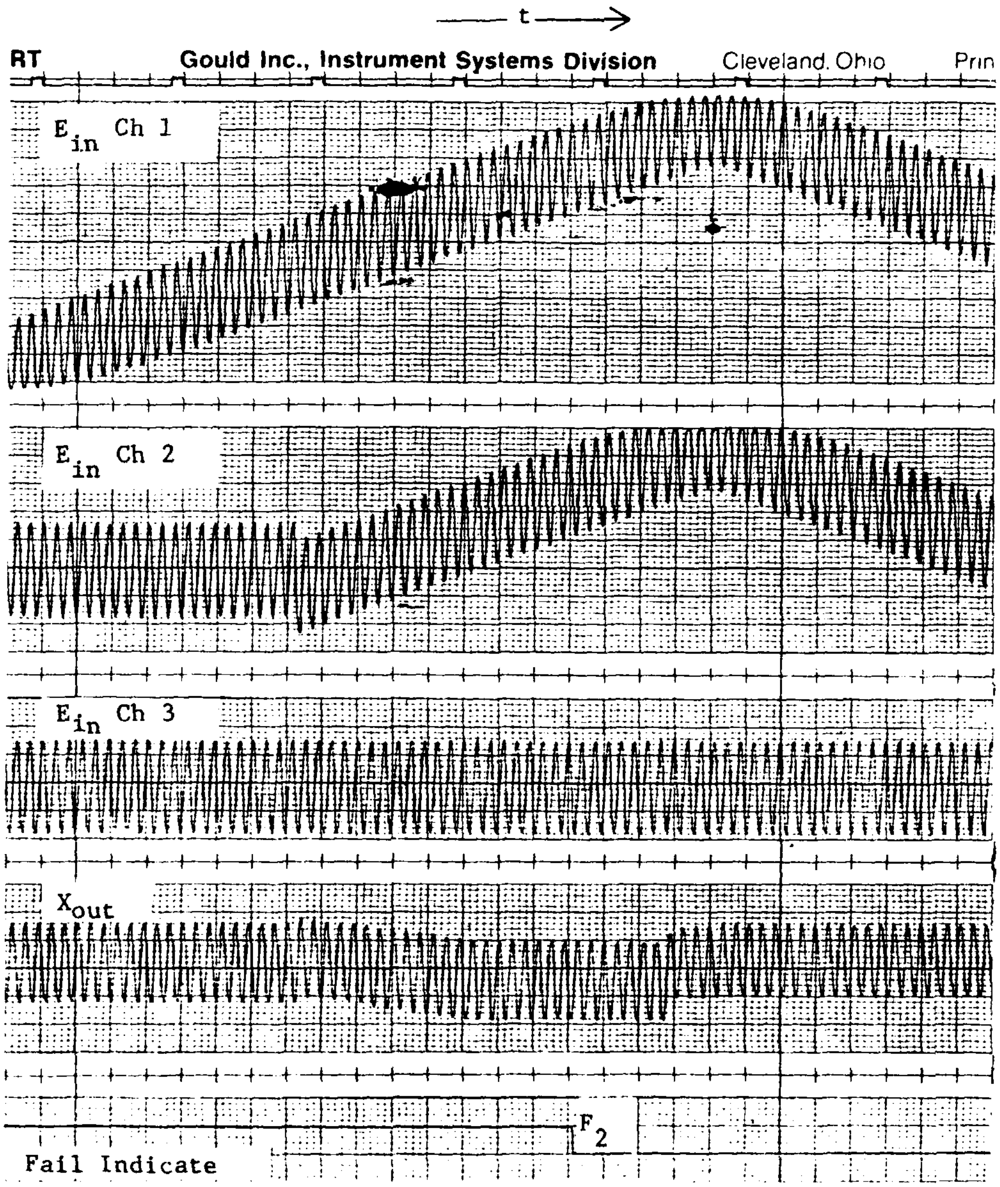
FIGURE 100 Failure Transients - Condition 29 (1 Chs. Retract)

# DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 6/5/79

TEST - Failure Transients - Condition 29 (2 Chs. Retract)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.0033 in/div
t = 20 div/sec

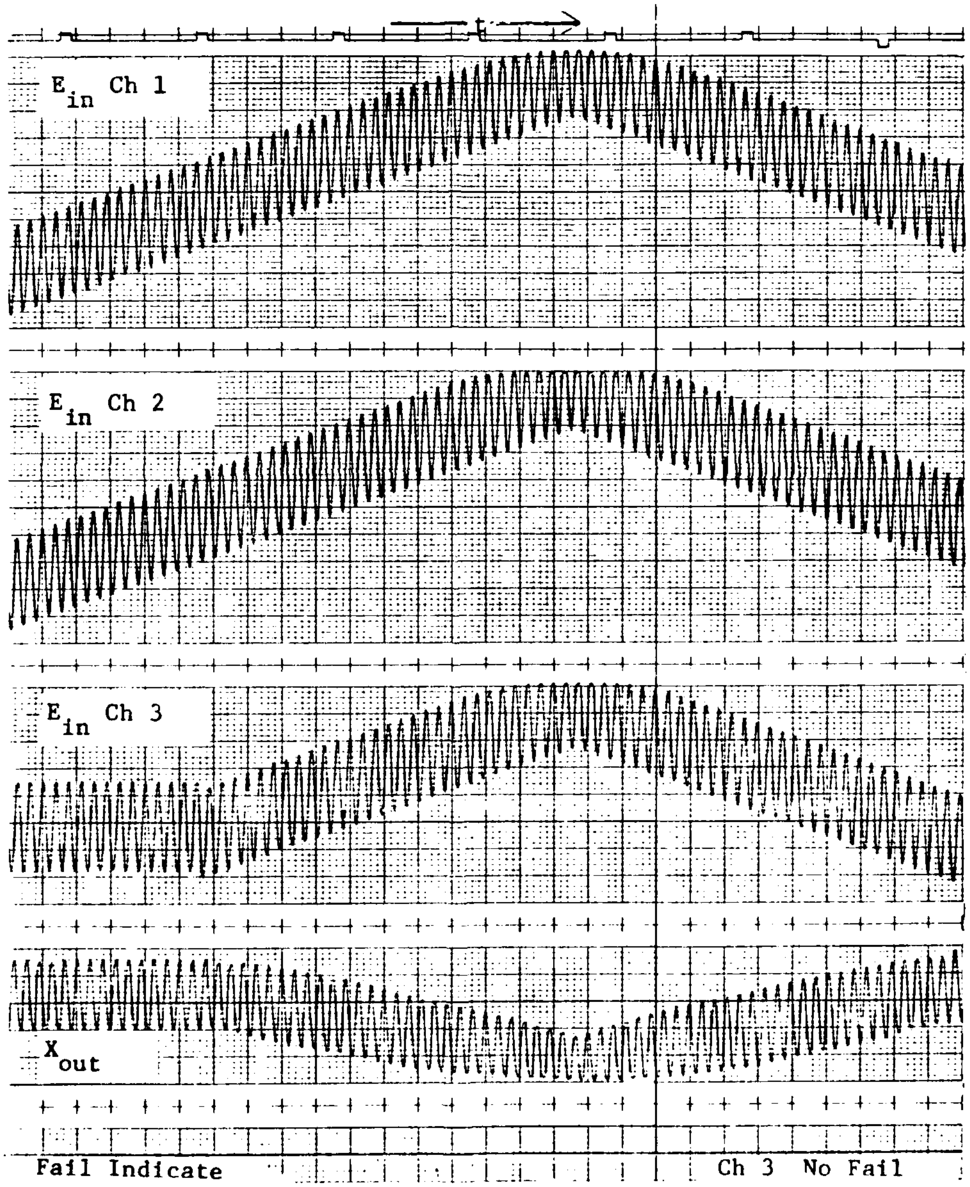
FIGURE 101 Failure Transients - Condition 29 (2 Chs. Retract)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 6/5/79

TEST - Failure Transients - Condition 29 (3 Chs. Retract)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.0033 in/div
t = 20 div/sec

FIGURE 102 Failure Transients - Condition 29 (3 Chs. Retract)

### 3.7.3.4 Hydraulic Failure Transient

Figures 103, 104 and 105 show the actuator deviation which occurs with failure of the hydraulic supply pressure to one or more channels of Configuration B. The configuration does not detect hydraulic failures as part of the design. Therefore, the effect of hydraulic failures on the system are essentially that of depressurizing the control actuator section connected to a particular hydraulic supply. Since the system could be connected with one separate hydraulic supply per channel or two channels to one supply and two channels to another, the transient testing evaluated both these supply pressure connections.

Figure 103 shows the effect of failing the hydraulic pressure to channel 1. The system does not show an output movement as a result of the hydraulic system failure. Note that no failure is voted by the failure logic, as was expected from the design of the system. Figure 104 shows the effect of sequentially failing the hydraulic pressure to channels 3 and 4 and then 1 and 2. The effect of the first failure is a slight shift of the actuator output, due to residual force fight between channels. Since channels 1 and 2, remaining operational after the first pressure failure, are depressurized together, no output deviation occurs with the second supply pressure failure. Note that after the second failure of the supply pressure, Configuration B is totally non-operational. Figure 105 shows the effect of total system failure with a null input. No significant deviation of the system output occurs.

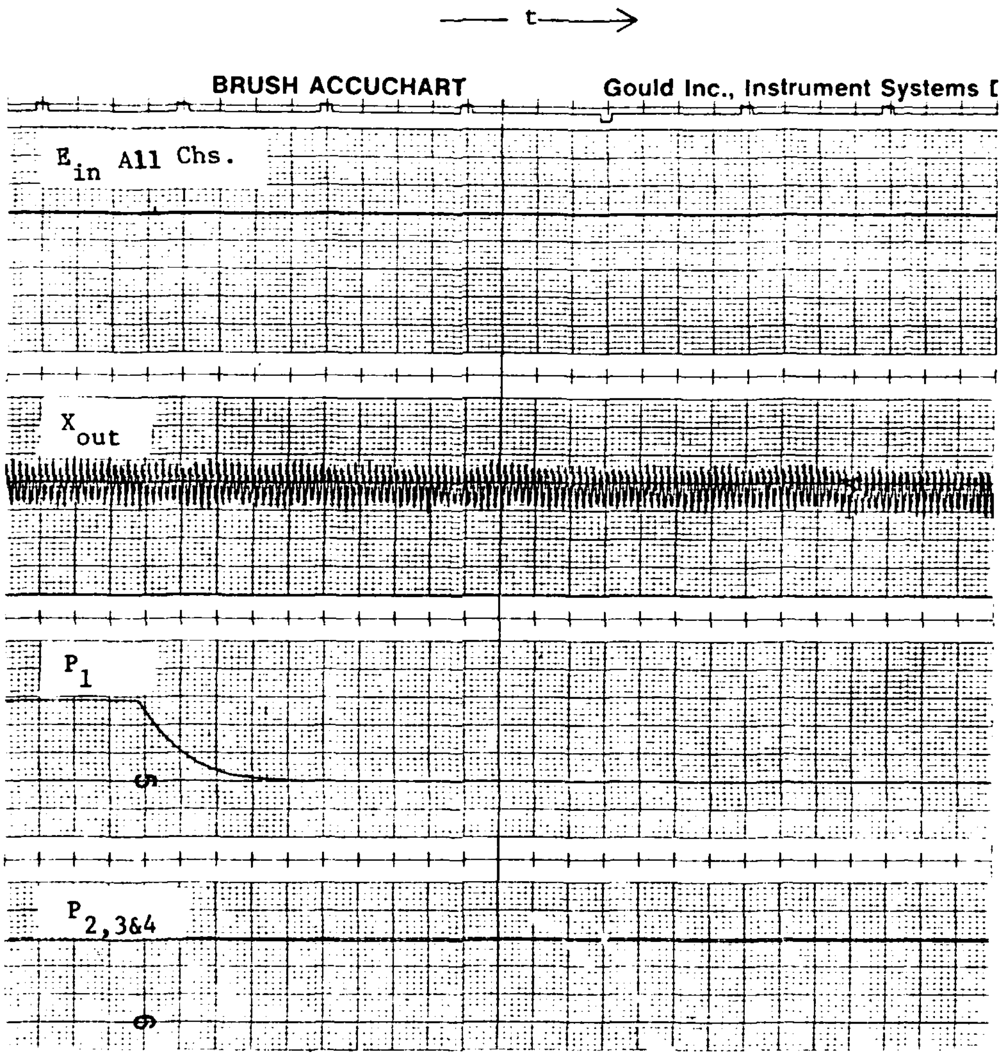
This test sequence for transients was not conducted on Configuration A. The general effect of hydraulic pressure failure is that of depressurization of the control channel without failure indication or activation of channel 4.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 6/6/79

TEST - Failure Transients - Condition 30




Scale: $E_{in}$ = 0.100 v/div
$X_{out}$ = 0.00003 in/div
$P_1$ = 200 psi/div
$P_{2,3\&4}$ = 200 psi/div
t = 20 div/sec

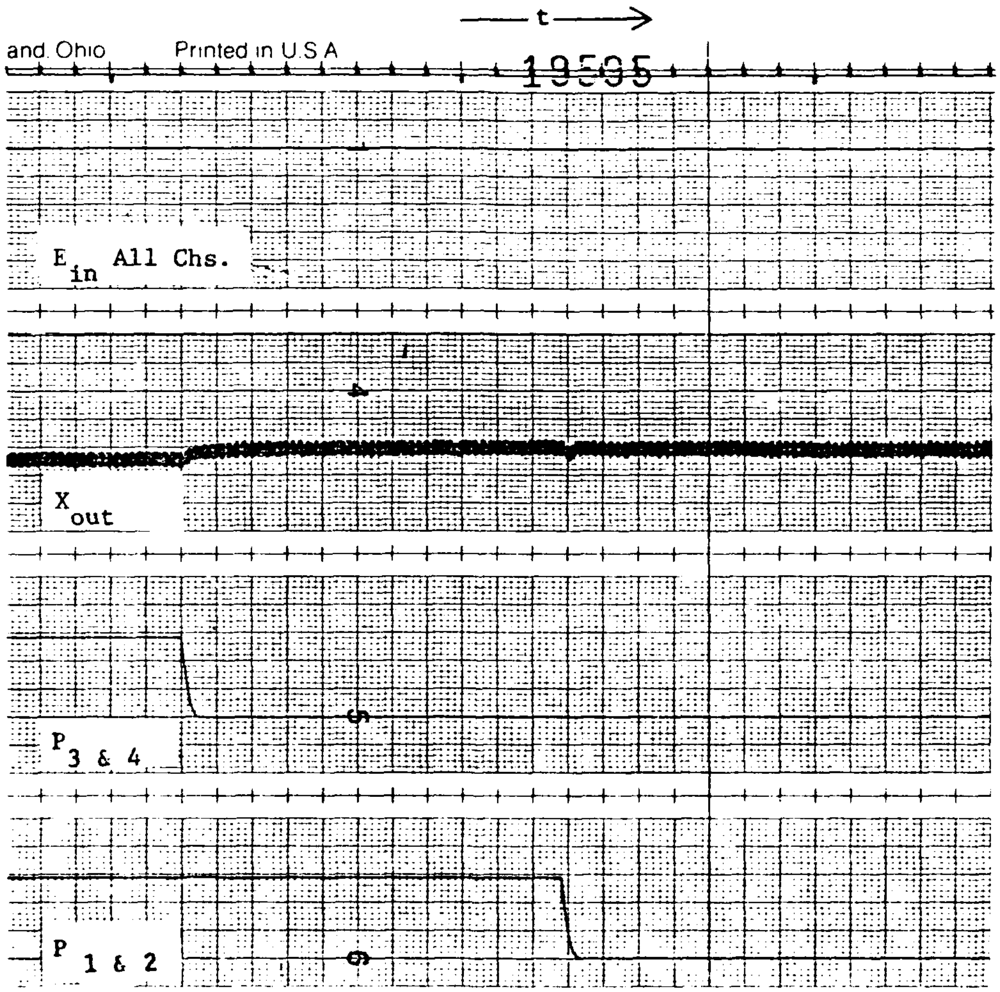
FIGURE 103 Failure Transients - Condition 30

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 6/6/79

TEST - Failure Transients - Condition 31




Scale: $E_{in}$ = 0.100 v/div
$X_{out}$ = 0.00013 in/div
$P_{3\&4}$ = 200 psi/div
$P_{1\&2}$ = 200 psi/div
t = 5 div/sec

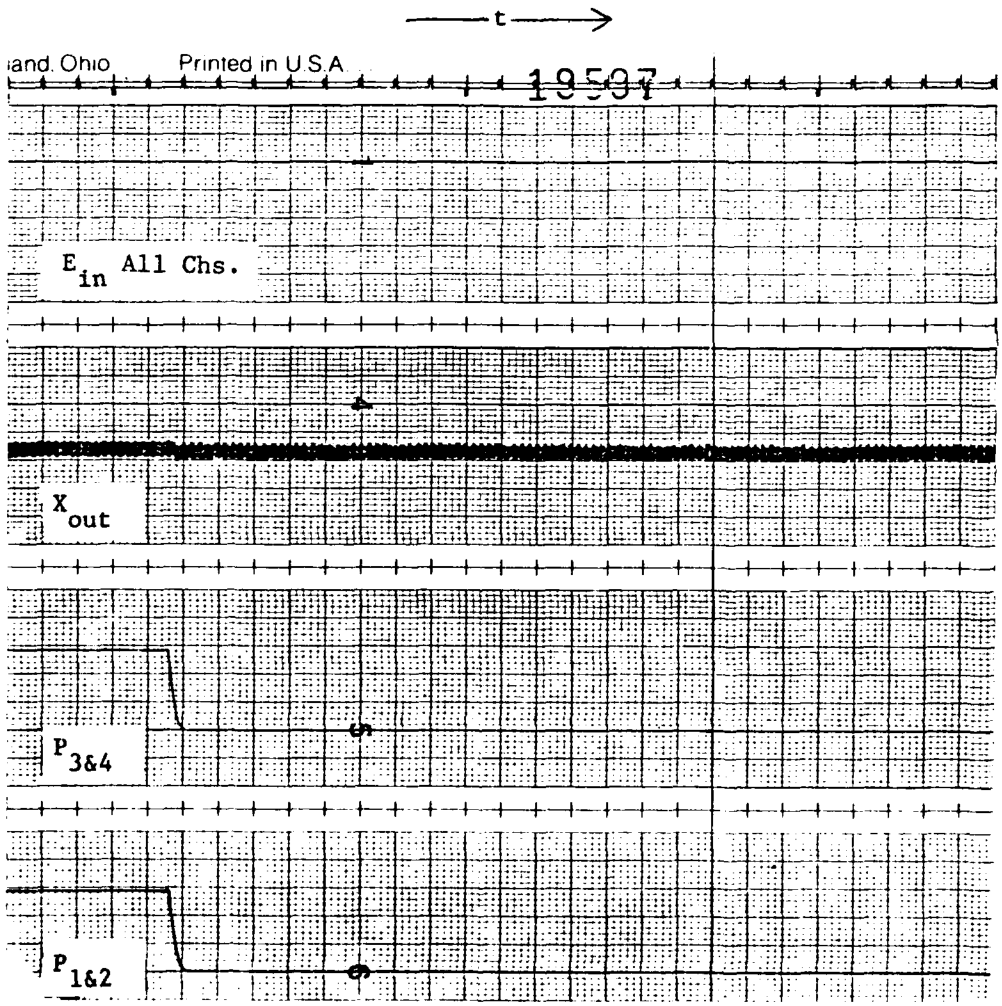
FIGURE 104 Failure Transients - Condition 31

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 6/6/79

TEST - Failure Transients - Condition 32




Scale: $E_{in}$ = 0.100 v/div
$X_{out}$ = 0.00013 in/div
$P_{3\&4}$ = 200 psi/div
$P_{1\&2}$ = 200 psi/div
t = 5 div/sec

FIGURE 105 Failure Transients - Condition 32

### 3.7.4 Failure Logic Detection Characteristics

#### 3.7.4.1 General

This section describes the results of testing conducted to establish the failure detection characteristics of Configuration B. The amplitude and duration of the transients resulting from control channel failures are directly affected by the failure detection characteristics. Also affected is the ability of a configuration to tolerate power and command signal momentary interrupts and amplitude transients. The detection levels used are the same as set for Configuration A (failure detection at channel mismatches corresponding to a servovalve current 50% of saturation). The time delays used were those initially provided with the unit and the same as Configuration A.

The test results present both the static detection level for each channel and the highest frequency at which an input amplitude 110% of the static detection level is detected by each channel and causes the channel to be depressurized.

#### 3.7.4.2 Specific

Figure 106 shows the data taken in order to establish the failure detection level for channels 1, 2 and 3 while the other input channels are grounded. The amplitude of the input at failure indication is the failure detection level.

Table 17 lists the extend and retract direction failure detection input voltages for each channel of Configuration B. Note that the channel 4 failure detection is lower than that of channels 1, 2 and 3 for the extend polarity of input voltage. For the measurement of channel 4's failure detection level, all other channels are operational and the force limit for channel 4 is 50%. The force limit establishes the differential pressure at which the equalizer-failure detection spool begins to move. It is expected that the failure detection level for channel 4 would increase with the increase in the channel 4 force limit to 100%.

Compared to Configuration A, the static failure detection level is greater for Configuration B. The increase in the static failure detection level is between 77% and 112% for all failure detection levels except the channel 2 and 3 retract failure detection levels. The increase over the Configuration A levels for those two voltages measured 35% and 31.6% respectively. The increase in the static failure detection level is a direct result of the differential pressure equalizer feedback circuit. This circuit requires a larger channel input for a given differential pressure (over the equalizer operating range) and would make the voltage required for a channel failure vote greater than without the equalizer operating.

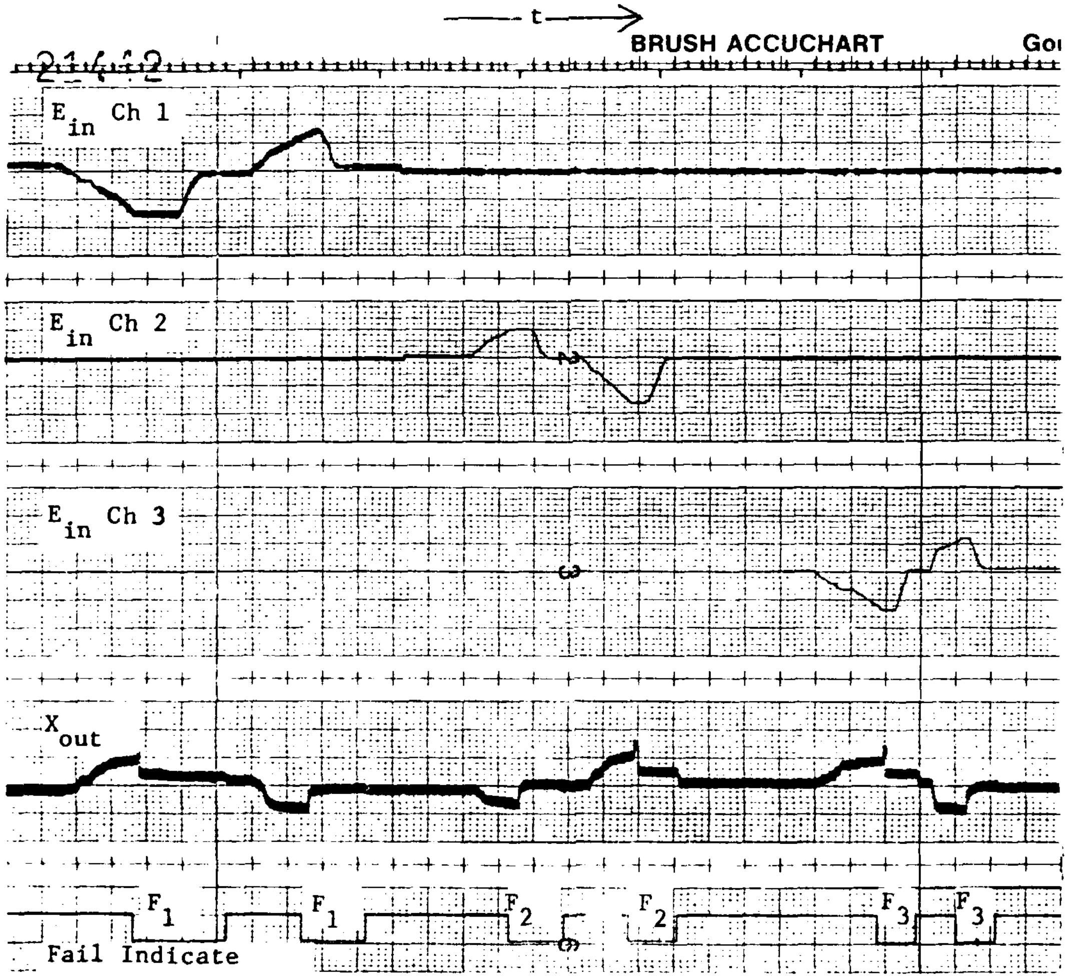
Figure 107 shows the test data obtained in measuring the channel 1, 2 and 3 dynamic failure detection level characteristics. The input to each channel is maintained at an amplitude of 110% of the input required to cause failure detection with a slowover input and the frequency of the input signal varied. As shown on Figure 107 the frequency of the input signal is reduced until the fail indicate data shows that a channel is voted as failed. Note that the fail indicate signal does not latch immediately with the first operation of the fail indicate output. The dynamic failure detection level bandpass frequency is defined as the frequency at which failure logic latches.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 6/27/79

TEST - Failure Detection Level - Static - Chs. 1, 2 & 3




Scale: $E_{in}$ = 0.[illegible]00 v/div
$X_{out}$ = 0.0133 in/div
t = 2 div/sec

FIGURE 106 Failure Detection Level - Static - Chs. 1, 2 & 3

TABLE 17

Failure Detection Level - Static

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 6/29/79

TEST ITEM - Grumman - Bertea Unit
Configuration B

TEST - Failure Detection Level - Static

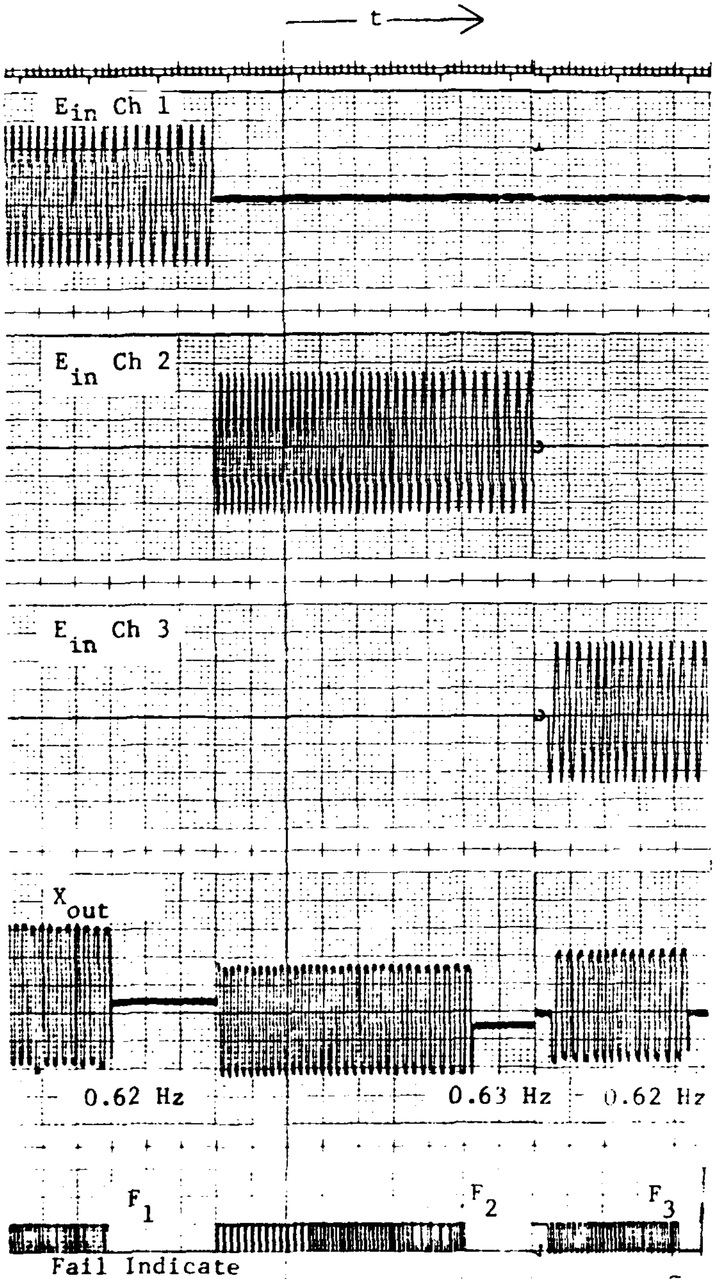
| Test Condition | Channel | Fail Voltage | |
|---|---|---|---|
| | | Extend | Retract |
| 1 | 1 | -0.800 | +0.650 |
| 1 | 2 | -0.800 | +0.500 |
| 1 | 3 | -0.700 | +0.500 |
| 1 | 4 | -0.250 | +0.550 |

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration B

Date
Prepared 6/27/79

TEST - Failure Detection Level - Dynamic - Chs. 1, 2 & 3




Scale: $E_{in}$ = 0.100 v/div
$X_{out}$ = 0.0007 in/div
t = 1 div/sec

FIGURE 107 Failure Detection Level - Dynamic - Chs. 1, 2 & 3

Table 18 lists the highest frequency at which the failure logic votes a failure for a particular channel with failure input amplitude 110% of the static failure detection level. For channels 1, 2 and 3, the frequency is .62 Hz. For channel 4, the frequency is .93 Hz. As with the static detection level, the difference between the channel 4 dynamic failure detection level and the dynamic detection level for channels 1, 2 and 3 is associated with the 50% force limit used with channel 4. It is expected that the detection level frequency would decrease for channel 4 to that of channels 1, 2 and 3 with an increase of the channel 4 force limit to 100%.

The failure detection highest frequency for Configuration B is approximately double that of Configuration A for channels 1, 2 and 3. The increase in frequency is due to the operation of the equalization feedback circuit. Since the equalization feedback requires a larger input for the same detection differential pressure, the available flow from the servovalve while developing the detection pressure level is increased compared to operating without the negative pressure feedback circuit connected. This allows the failure detection spool to reach the detection stroke at a higher frequency. This extention of the failure detection bandpass to a higher frequency than without the negative pressure feedback circuit is a positive aspect of the pressure feedback technique.

TABLE 18

Failure Detection Level - Dynamic

DYNAMIC CONTROLS, INC.

Test Data

Date Prepared 6/29/79

TEST ITEM - Grumman - Bertea Unit
Configuration B

TEST - Failure Detection Level - Dynamic

| Test Condition | Channel | Fail Hz |
|---|---|---|
| 1 | 1 | 0.62 |
| 1 | 2 | 0.63 |
| 1 | 3 | 0.62 |
| 1 | 4 | 0.93 |

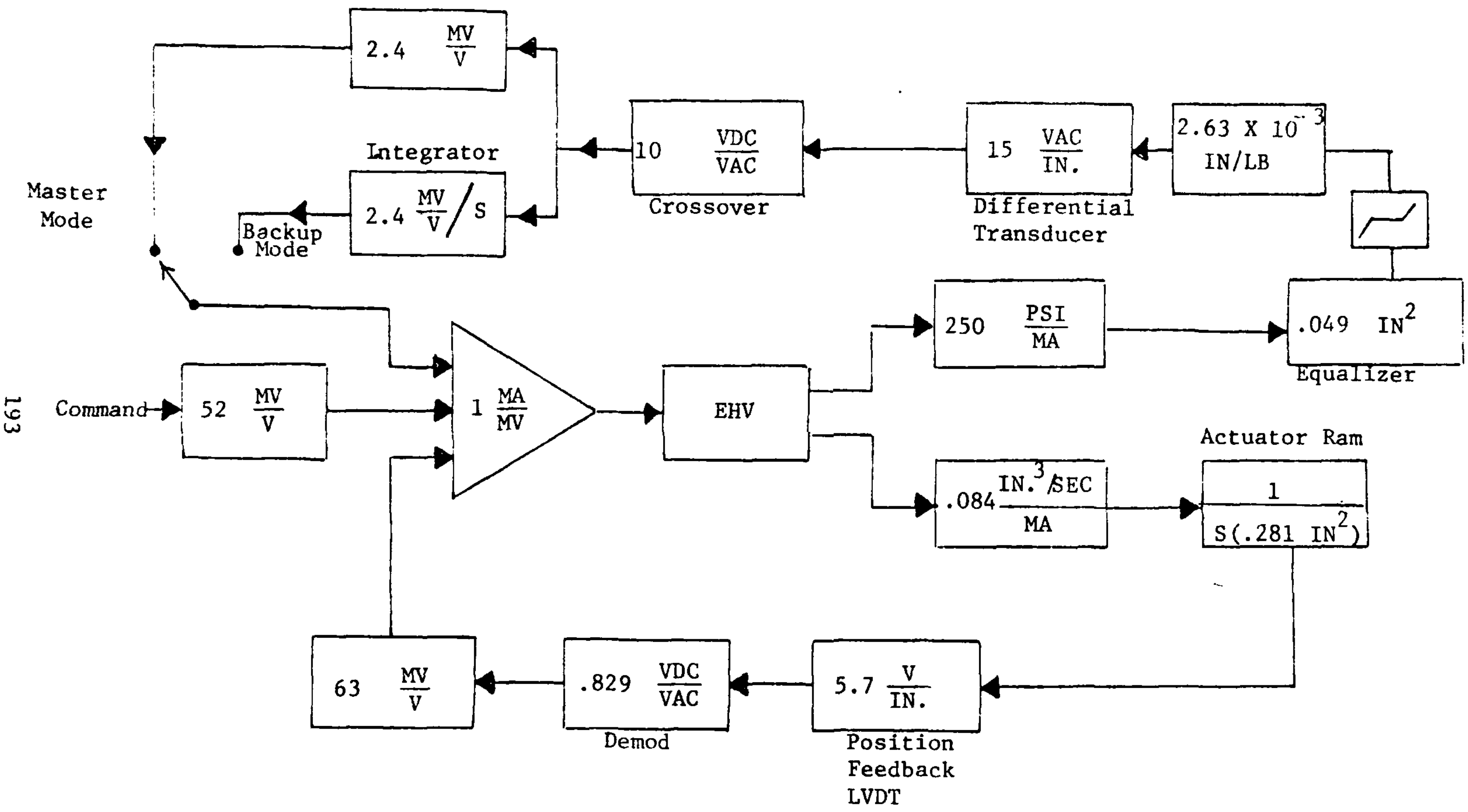



FIGURE 108 Control Channel Schematic - Force Sharing Demonstrator - Configuration C

## 3.8 Specific Test Procedure - Configuration C

### 3.8.1 General

Configuration C of the force sharing system is based on Configuration B with integrators being added to the equalizer feedback network. The purpose of adding integrators to the equalizers was to improve the threshold characteristics of the force sharing mechanization. The integrators allow the control channels to operate in the high pressure gain region of the control valves, even with large channel offsets. Figure 108 is a schematic of one Configuration C control channel. The channel is mechanized so that either proportional or integral equalizer feedback can be selected for the channel. All circuit values are the same as those used for Configuration B. No change in the logic failure detection settings were made in converting Configuration B to Configuration C.

For channel offsets, the effect of the integrators used with the equalizers is to drive the differential pressure across the equalizers to that corresponding to the spring preload level. This allows the control channels to operate in the high pressure gain region of the control valves. This is because the equalizer does not reduce the pressure gain of a control valve when the differential pressures are below the spring preload level for the equalizer. The net effect of integrating the equalizer output with the force sharing channels coupled together is to cause the effective pressure gain of the system to be greater than that occurring with the proportional equalizer feedback technique.

Figure 109 shows the expected effect on the channel offsets of adding the integrators to the equalizer outputs. Note that for the channels having offsets which cause differential pressures greater than that equivalent to the equalizer spring preload, the differential pressures are driven towards the spring preload pressure level. For the channel with an initial differential pressure below the equivalent spring preload pressure, the pressure changes slightly. This change is due to the reduction in the differential pressures of the other channels (1, 2 and 4) in response to the equalizer integration operation.

In order to avoid having the output position of the control system dominated by the operation of integrated equalizer feedback loop, it is necessary to operate one control channel of the system as a master channel without equalizer output integration. This master channel determines the system output position and the remaining channels tend to adjust themselves to minimize a force fight with the master channel. In order to maintain a master channel with each system failure, the failure logic is modified to reassign the master channel role to one of the remaining good channels upon failure of a control channel. As mechanized for Configuration C, Channel 1 is assigned the role of the master channel with no failures. With the failure of channel 1, channel 2 is assigned the role of the master channel. For first failures other than channel 1, the master channel assignment remains with channel 1. Channel 3 is used as the 3rd master channel if both channels 1 and 2 fail.

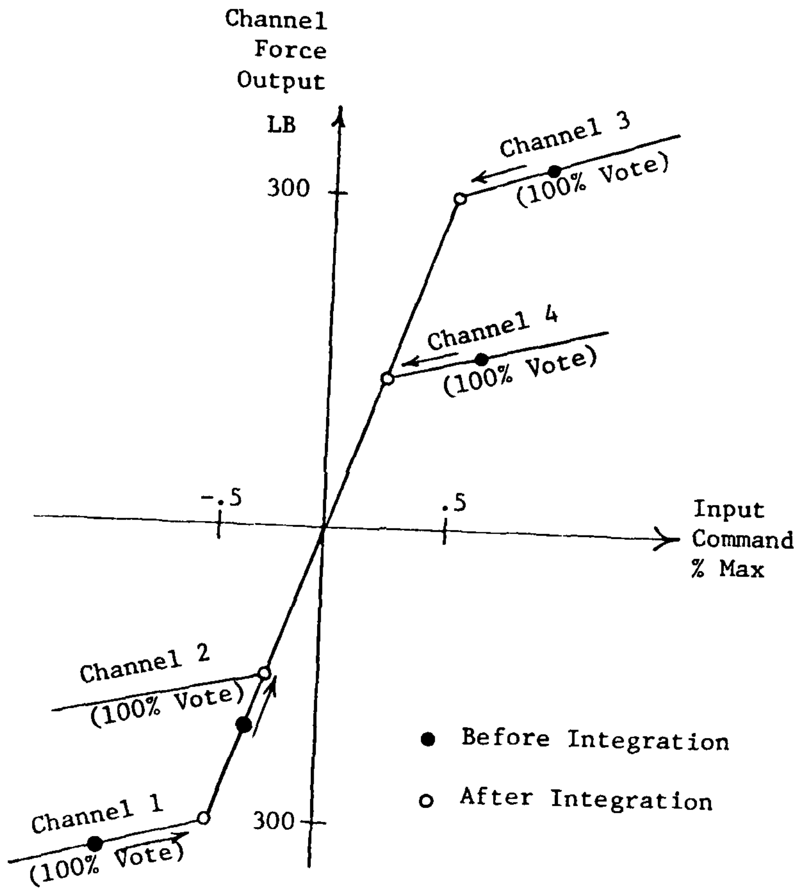



FIGURE 109 Integrator Effect On Channel Offsets

The threshold characteristics are potentially improved by the use of the integrator and master channel approach because of the improvement in the effective pressure gain. The use of the integrator in the pressure equalizer feedback path does require integrator saturation before slowover failures having a rate of change slower than the integration rate can be detected. This results in an input amplitude for failure detection greater than the amplitude for slowover failures having a rate of change greater than the integration rate. The system output deviation for either slowover failure should be the same, since the actuator channel force output at failure detection is unchanged by the operation of the integrator.

In general, the effect of failures on the actuator output deviation should be improved by the operation of the integrators. This is because the integrators force the backup channels (those using the integrated equalizer feedback) to operate in or at the edge of the high pressure gain region. Therefore, a channel failure is required to create less actuator output change before causing an opposing force fight (and failure detection) than with the non-integrated equalizer outputs. With the non-integrated equalizer outputs, the channels can operate (and normally do) away from the high force gain region. With a channel failure and non-integrator equalizers, the system output must change enough to cause the opposing channels to operate in or approach the high force gain region. This output change is added to the change required for actual force balancing with the failed channel.

The effect of a slowover input with a rate of change less than the integration rate into a master channel causes no problem and does not require the backup channel integrators to saturate in order to vote a master channel as failed. Force opposition is achieved at an output change less than that required for backup channel integrator saturation. This is illustrated on Figure 110. The initial positions of channels 1, 2, 3 and 4 are shown circled with a solid line. Note that the run of the positive and the negative channel forces is zero. Channel 4 operates at its 50% force limit and is assumed being at + 150 lb. Channel 1 is assumed to be the master channel. The change of position of the control channels upon a slowover input into channel 1 is shown with dotted lines. A positive drift of channel 1 is shown to the point of failure detection. Note that at failure detection, the other three channels have moved to keep the sum of the positive and negative forces equal to zero. Channel 2 moves to a -300 lb force position and because of the integrator operation remains at that force level. Note that channels 3 and 4 were initially operating at the edge of the high force gain region. They move towards a negative force output in response to the system output change resulting from the slowover input change to channel 1. The dotted circles indicate the respective channel positions upon detection of the channel 1 failure.

Note that the effect of the integration in this example is to limit the force of channel 2 to -300 lb, requiring channels 3 and 4 to shift more in order to create a force balance. The effect of no channel 2 integration would be to allow channel 2 to move to a slightly more negative force with increasing output deviation. However, because the channel 2 movement would be in a low force gain region, the relative reduction in actuator movement for force balancing and failure detection of the channel 1 failure would be slight.

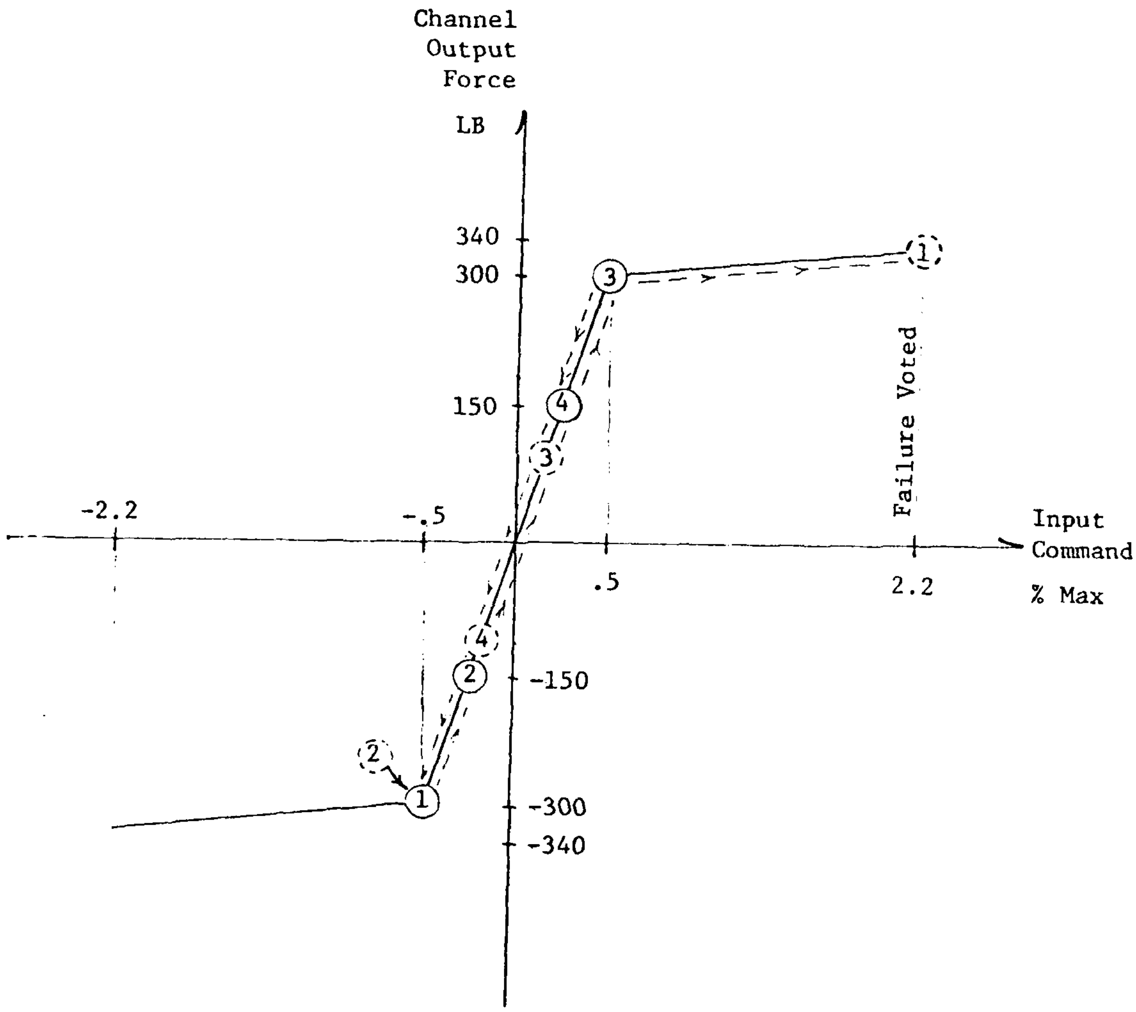



FIGURE 110 Slowover Failure Detection - Master Channel - Configuration C

3.8.2 Specific

The test procedure used for evaluation of Configuration C was similar to that used for Configuration A and B. Table 19 lists the 27 test conditions and the values used for evaluating Configuration C.

The test Conditions 1 through 11 are the various operational modes of the system. The performance measurements described in Section 2.2.1 were used to document the performance characteristics for these test conditions. All other test conditions correspond to the "Failure Effect on Performance" measurements described in Section 2.2.2 and the "Input Deviations Effect" measurements described in Section 2.2.3.

Test Conditions 12 through 27 correspond to the "Failure Removal Transients" measurements described in Section 2.2.4. These test conditions describe both the initial conditions and the test used for creating the transient.

## 3.9 Test Results

3.9.1 General

The data presentation format for the test results of Configuration C is the same as for Configuration A and B. For all measurements except the transient measurements, the test data is presented in tabular form. For the transient data, the results are presented as recorded.

TABLE 19

TEST CONDITIONS

Grumman - Bertea Unit - Configuration C

| Test Condition | Test Condition Description |
|---|---|
| 1 | Baseline - all channels nulled, pressurized (3000 psi) and operating correctly. |
| 2 | One channel (1) electrical failure. |
| 3 | Two channels (1 & 2) electrical failure. |
| 4 | One channel (1) hydraulic failure. |
| 5 | Two channels (1 & 2) hydraulic failure. |
| 6 | One channel (1) with negative input offset (biased to 90% of trip level). |
| 7 | One channel (1) with positive input offset biased to 90% of trip level). |
| 8 | Two channels (1 & 2) with negative input offsets (both channels biased negatively to 90% trip level). |
| 9 | Two channels (1 & 2) with opposing input offsets (channel 1 biased positively and channel 2 biased negatively to 90% trip level). |
| 10 | One channel (1) with hydraulic pressure reduced to 2000 psi. |
| 11 | Two channels (1 & 2) with hydraulic pressure reduced to 2000 psi. |
| | FAILURE TRANSIENTS |
| 12 | Ground inputs to channels 1, 2 & 3 sequentially with system at 50% extend. |
| 13 | Ground inputs to channels 1, 2 & 3 sequentially with system at 50% retract. |

TABLE 1

TEST CONDITIONS (cont'd)

| Test Condition | Test Condition Description |
|---|---|
| 14 | Ground inputs to channels 1, 2 & 3 sequentially with the system operating at ½ the bandpass frequency (10 Hz) with the maximum unsaturated input. |
| 15 | Ground the inputs to channels 1 & 2 simultaneously with the system operating at ½ the bandpass frequency (10 Hz) with the maximum unsaturated input amplitude. |
| 16 | Positive hardover (+10V) sequentially applied to channels 1, 2 & 3 with the system at null. |
| 17 | Negative hardover (-10V) sequentially applied to channels 1, 2 & 3 with the system at null. |
| 18 | Positive hardover (+10V) sequentially applied to channels 1, 2 & 3 with the system biased to 50% extend. |
| 19 | Negative hardover (-10V) sequentially applied to channels 1, 2 & 3 with the system biased to 50% extend. |
| 20 | Positive hardover (+10V) sequentially applied to channels 1, 2 & 3 with system biased to 50% retract. |
| 21 | Negative hardover (-10V) sequentially applied to channels 1, 2 & 3 with system biased to 50% retract. |
| 22 | Positive hardover (+10V) sequentially applied to channels 1, 2 & 3 with system operating at ½ the bandpass frequency (10 Hz) with the maximum unsaturated input amplitude. |
| 23 | Negative hardover (-10V) sequentially applied to channels 1, 2 & 3 with system operating at ½ the bandpass frequency (10 Hz) with the maximum unsaturated input amplitude. |

TABLE 1

TEST CONDITIONS (cont'd)

| Test Condition | Test Condition Description |
|---|---|
| 24 | Positive hardover (+10V) simultaneously to channels 1 & 2 with the system at null. |
| 25 | Positive hardover (+10V) simultaneously to channels 1 & 2 with the system operating at ½ the bandpass frequency (10 Hz) with the maximum unsaturated input amplitude. |
| 26 | Apply a ramp of zero to 1 volt at 0.4 volts/sec ($\pm$1.0V at 0.1 Hz) to channels 1, 2 & 3 sequentially with system at null. |
| 27 | Apply a ramp of 0 to 1 volt at 0.4 volts/sec ($\pm$1.0V at 0.1 Hz) sequentially to channels 1, 2 & 3 with system operating at ½ the bandpass frequency (10 Hz) with the maximum unsaturated input amplitude. |

The non-detection of hydraulic failures by the force sharing system affected the testing of Configuration C. As mechanized, a hydraulic failure of a master channel did not cause transfer of the master role to a backup channel. For Condition 4 of Table 19, the hydraulic failure of channel 1 allowed the system output to drift in response to the integrator operation. Since this condition was not considered to be representative of the mechanization approach and could be solved by the addition of pressure sensing logic, no test results are shown for Condition 4. Condition 5, with the hydraulic failure of both channels 1 and 2, did produce test data which are included in the test results. Although the hydraulic failure of channels 1 and 2 did not cause the existing logic to make channel 3 or 4 a master channel, the 50% force limit for channel 4 caused channel 3 to operate in its high force gain region in order to achieve an equilibrium condition. This effectively caused channel 3 to operate as a non-integrated or master channel.

The following results are presented in tabulated form for conditions 1 through 11 (with the exception of Condition 4):

1. Static Threshold
2. Dynamic Threshold
3. Frequency Response
4. Distortion
5. Hysteresis
6. Saturation Velocity

For these test results reduced to tabular form, a sample of the recorded data is included with the table. The linearity and step responses for conditions 1 through 11 are presented as recorded.

As was done for Configuration A and B, the measurements of threshold and hysteresis are presented in terms of both the percent of the input required for full actuator stroke and the input required for full servovalve output flow. As previously stated, this method of presenting the data allows comparing different control valve driving mechanizations independent of the actuator stroke used for the mechanization. The test results for Configuration C are presented as follows:

1. Performance measurements for Conditions 1 through 11 (with condition 4 omitted)
2. Failure transients for Conditions 1 through 11 (with Condition 4 ommitted).
3. Failure logic detection characteristics.

As appropriate, the test results are discussed in comparison with those obtained for Configuration A and B.

### 3.9.2 Performance Measurements

#### 3.9.2.1 Static Threshold

Figure 111 shows the data recorded in establishing the static threshold for Configuration C and test Condition 1. As shown on this figure, the amplitude of the ramp input is increasing with increasing time. The threshold value is determined by the amplitude of the input where the actuator output starts to respond to the input signal. Table 20 lists the threshold values measured for the test conditions 1 through 11 (with ondition 4 omitted).

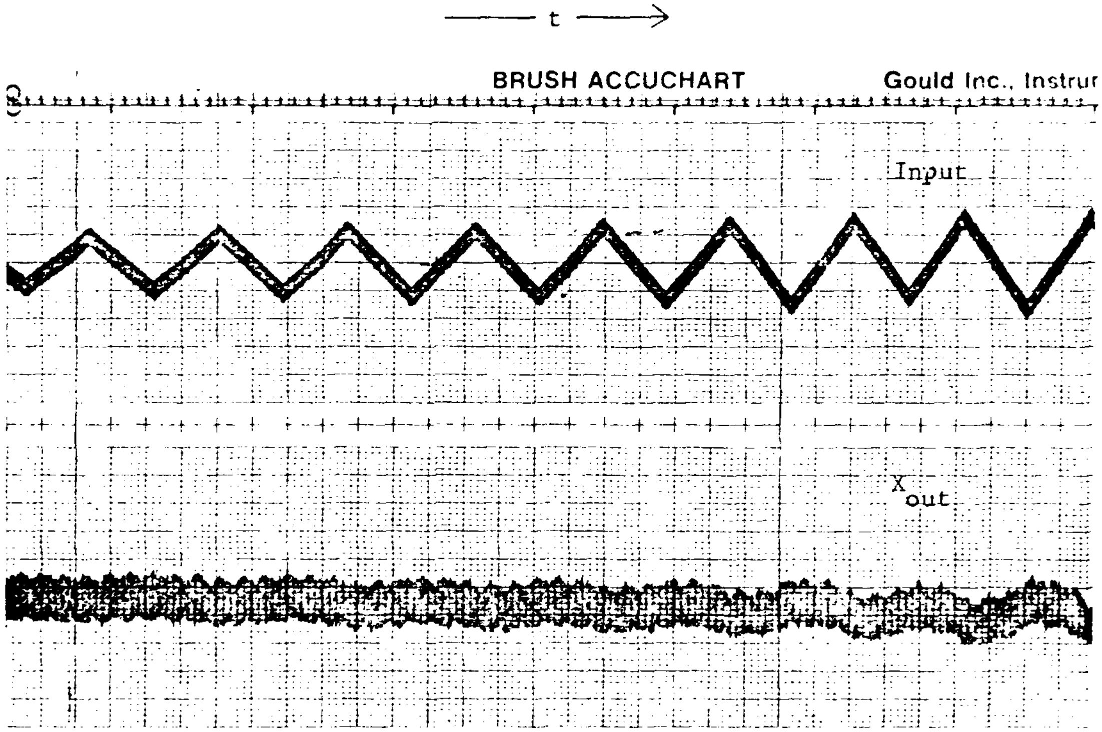
The threshold measured for Configuration C was generally better than for Configuration B and slightly worse than Configuration A. Since the intent of the addition of the integrators to the force mechanization (in order to make Configuration C) was to improve the threshold, the results are significant.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date
Prepared 4/24/79

TEST - Static Threshold - Condition 1




0.1 Hz Ramp Input

Scale: Input = 0.0002 v/div

$X_{out}$ = 0.00003 in/div

t = 2 div/sec

FIGURE 111 Static Threshold - Condition 1

TABLE 20

STATIC THRESHOLD

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 4/18/79

TEST ITEM - Grumman - Bertea Unit
Configuration C

TEST - STATIC THRESHOLD

| Test Condition | Input Volts | Static Threshold % of Max Input | Static Threshold % of $E_v$ Max |
|---|---|---|---|
| 1 | 0.028 | 0.14 | 18.21 |
| 2 | 0.036 | 0.18 | 23.41 |
| 3 | 0.042 | 0.21 | 27.31 |
| 4 | | | |
| 5 | 0.041 | 0.21 | 26.66 |
| 6 | 0.051 | 0.25 | 33.16 |
| 7 | 0.028 | 0.14 | 18.21 |
| 8 | 0.039 | 0.19 | 25.36 |
| 9 | 0.036 | 0.18 | 23.41 |
| 10 | 0.038 | 0.19 | 24.71 |
| 11 | 0.036 | 0.18 | 23.41 |

For the normal operating Condition 1, the threshold was 70% of that measured for the same test condition and Configuration B. The threshold was 27% greater than that measured for Condition 1 and Configuration A. This trend, with few exceptions, continues for the remaining test Conditions 2 through 11. It appears from these test results that the integration of the equalizer outputs does make some improvement to the force gain of the system with the pressure equalizer feedback connected. However, the threshold without any equalizer feedback (Configuration A) is still generally lower than for Configuration C.

### 3.9.2.2 Dynamic Threshold

Figure 112 shows the data recorded in establishing the dynamic threshold for Condition 1. A 10 Hz input of nominal sinusoidal form was used to drive the actuator system. The input waveform shows some generator distortion pecular at that time to the function generator used for the testing.

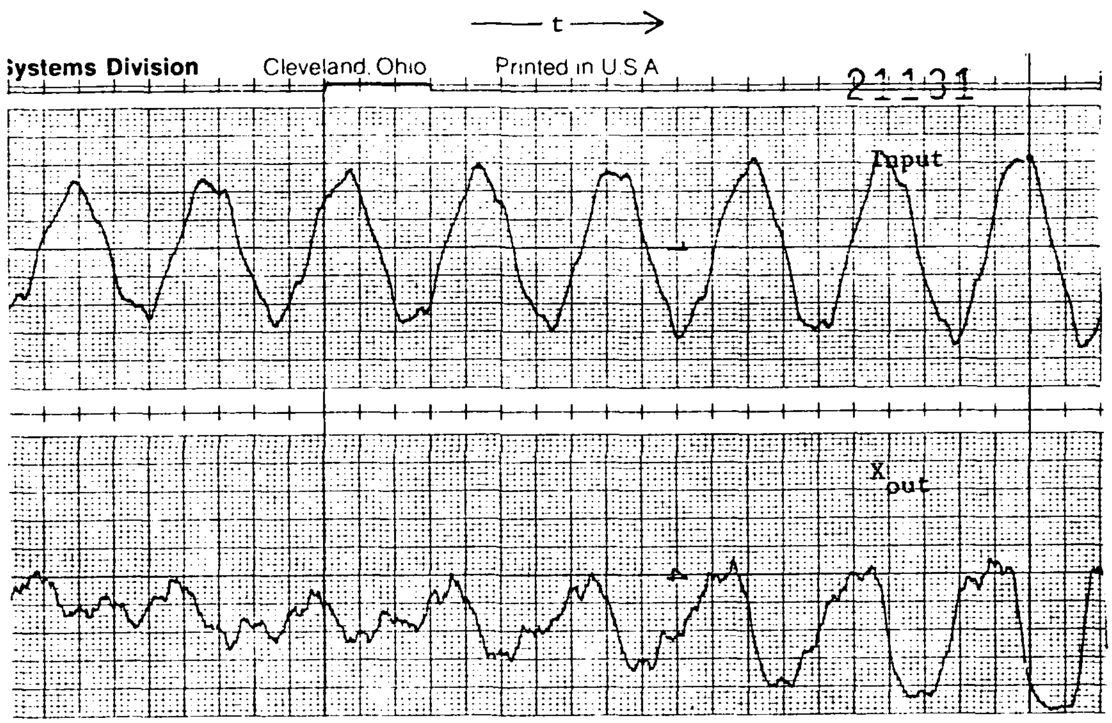
Table 20 lists the dynamic threshold measurements for Configuration C and test Conditions 1 through 11 (Condition 4 omitted). The dynamic threshold varies from .066 to .155 volts at the input. Compared to the dynamic threshold range for Configuration B of .034 to .046 volts, the Configuration C dynamic threshold values are almost twice as large. This indicates that the operating points for the control channels are such that the force gain from the servovalves is lower than with Configuration B. The Configuration C measurements are also larger than those for Configuration A (except for Conditions 3 and 11).

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date
Prepared 4/25/79

TEST - Dynamic Threshold - Condition 1




10.0 Hz Sine Wave Input

Scale: Input = 0.002 v/div

$X_{out}$ = 0.00003 in/div

t = 200 div/sec

FIGURE 112 Dynamic Threshold - Condition 1

TABLE 21

Dynamic Threshold

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 4/18/79

TEST ITEM - Grumman - Bertea Unit
Configuration C

TEST - DYNAMIC THRESHOLD

| Test Condition | Input Volts | Dynamic Threshold % of Max Input | Dynamic Threshold % of $E_v$ Max |
|---|---|---|---|
| 1 | 0.066 | 0.33 | 42.91 |
| 2 | 0.077 | 0.38 | 50.07 |
| 3 | 0.074 | 0.37 | 48.11 |
| 4 | | | |
| 5 | 0.150 | 0.75 | 97.53 |
| 6 | 0.155 | 0.77 | 100.78 |
| 7 | 0.090 | 0.45 | 58.52 |
| 8 | 0.073 | 0.37 | 47.46 |
| 9 | 0.080 | 0.40 | 52.02 |
| 10 | 0.072 | 0.36 | 46.81 |
| 11 | 0.066 | 0.33 | 42.91 |

The net effect of the equalizer integration on the dynamic threshold characteristics is one of degradation compared to operation without the integrators. This was not anticipated for the test results and is apparently due to the particular operating offset conditions for the channels causing a slight reduction in the force available from the servovalves when meeting the dynamic flow demand for the individual channels.

### 3.9.2.3 Frequency Response

Figure 113 shows the frequency response recorded for the condition 1 response measurements. As with the tests for Configurations A and B, the response for all test conditions resembled the response shown on Figure 113 in terms of the peaking and roll-off characteristics.

Table 22 lists the frequency response for Conditions 1 through 11 (Condition 4 omitted) in terms of the frequencies at which the $-90^{\circ}$ phase angle and the -3 Db amplitude ratio point occurred for each test condition. As shown on Table 22, the -3 Db frequencies did not vary significantly for the various test conditions. The lowest -3 Db frequency was 17 Hz and the highest 19.8 Hz. These results are similar to those obtained for Configurations A and B. Since the integrators are only effective at very low frequencies, little effect on the frequency response of the system was expected. The test results for the frequency response are consistent with the effect expected of the integrators.

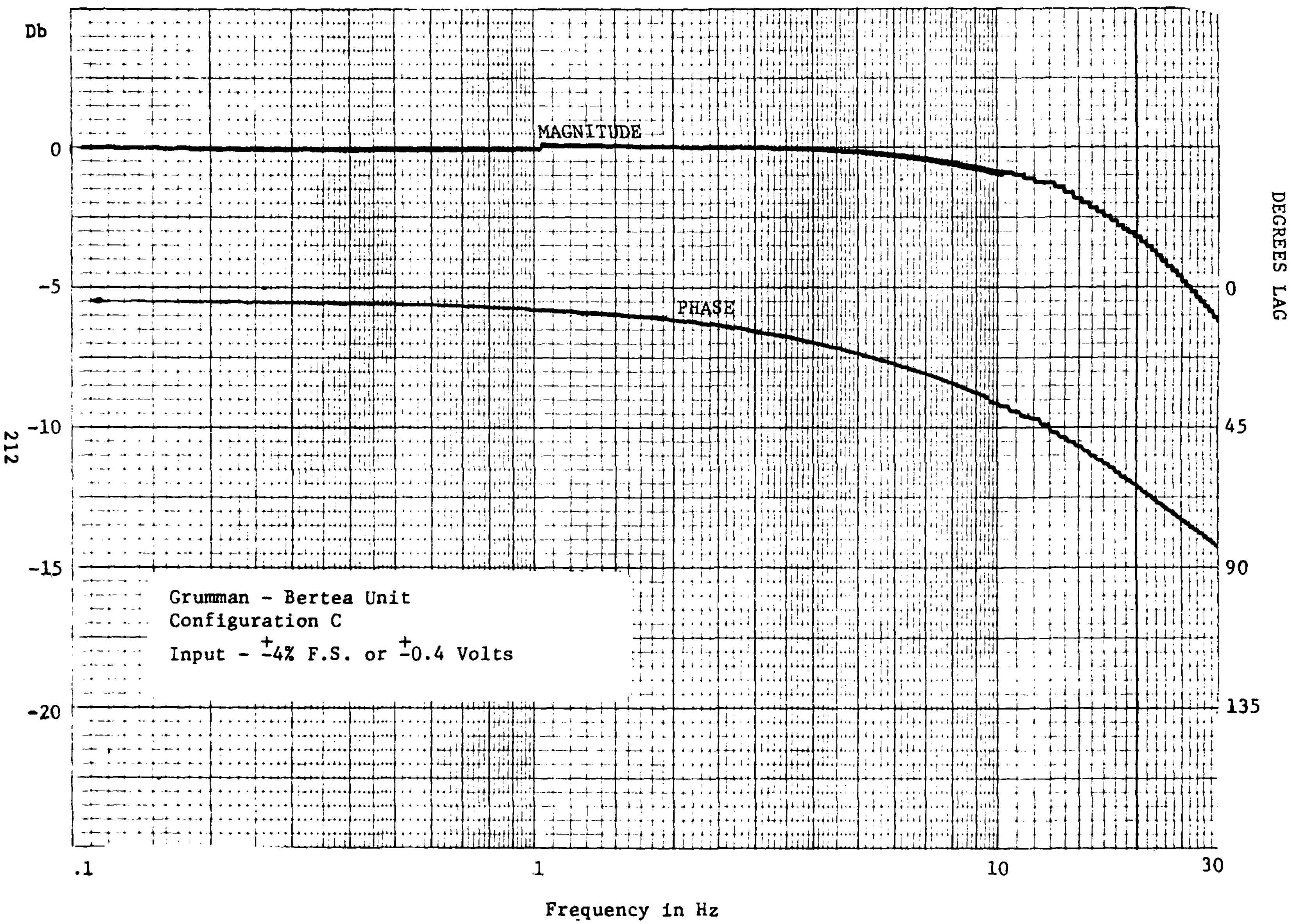



FIGURE 113 Frequency Response - Condition 1

TABLE 22

Frequency Response

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 4/18/79

TEST ITEM - Grumman - Bertea Unit
Configuration C

TEST - FREQUENCY RESPONSE

| Test Condition | Output 4% Full Scale -3 db Hz | -90$^{\circ}$ Hz |
|---|---|---|
| 1 | 19.0 | 34.0 |
| 2 | 19.8 | 34.0 |
| 3 | 18.8 | 31.5 |
| 4 | | |
| 5 | 18.3 | 30.0 |
| 6 | 18.8 | 32.5 |
| 7 | 18.8 | 32.5 |
| 8 | 18.3 | 33.0 |
| 9 | 19.0 | 32.5 |
| 10 | 17.5 | 32.0 |
| 11 | 17.0 | 32.0 |

### 3.9.2.4 Distortion

Table 23 lists the harmonic distortion measured on Configuration C for test Conditions 1 through 11 (Condition 4 ommitted). At 5 Hz the distortion is approximately two thirds that measured on Configurations A and B. At 10 Hz the distortion was still lower by a factor of one third that measured on Configuration B and by one fifth than that measured for Configuration A for most of the test conditions. At 20 Hz, the distortion was similar to that of Configuration B and slightly higher than that measured for Configuration A. The distortion for all test conditions and frequencies did not exceed 6%, indicating good signal transmission fidelity.

Condition 5 with two channels failed hydraulically gave the highest distortion figures for Configuration C at all three test frequencies. This is consistent with test condition since the available driving force to move the output had been reduced to less than half the no failure condition (Condition 1).

For the test data, it is apparent that the operation of the integrators with the pressure equalization feedback does not adversely affect the system distortion.

TABLE 23

Distortion

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 4/19/79

TEST ITEM - Grumman - Bertea Unit
Configuration C

TEST - DISTORTION

| Test Condition | Change of % distortion from baseline value | | |
|---|---|---|---|
| | % @ 5 Hz | % @ 10 Hz | % @ 20 Hz |
| 1 | Baseline Value* | Baseline Value** | Baseline Value*** |
| 2 | 0.10 | 0.40 | -0.04 |
| 3 | 0.74 | 1.10 | 0.70 |
| 4 | | | |
| 5 | 1.00 | 1.20 | 1.49 |
| 6 | 0.15 | 0.16 | 0.28 |
| 7 | 0.15 | -0.04 | 0.18 |
| 8 | 0.26 | 0.67 | 0.29 |
| 9 | 0.26 | 0.18 | -0.07 |
| 10 | 0.06 | 0.78 | -0.21 |
| 11 | 0.16 | 1.08 | 0.49 |

*2.26% **2.78% ***4.19%

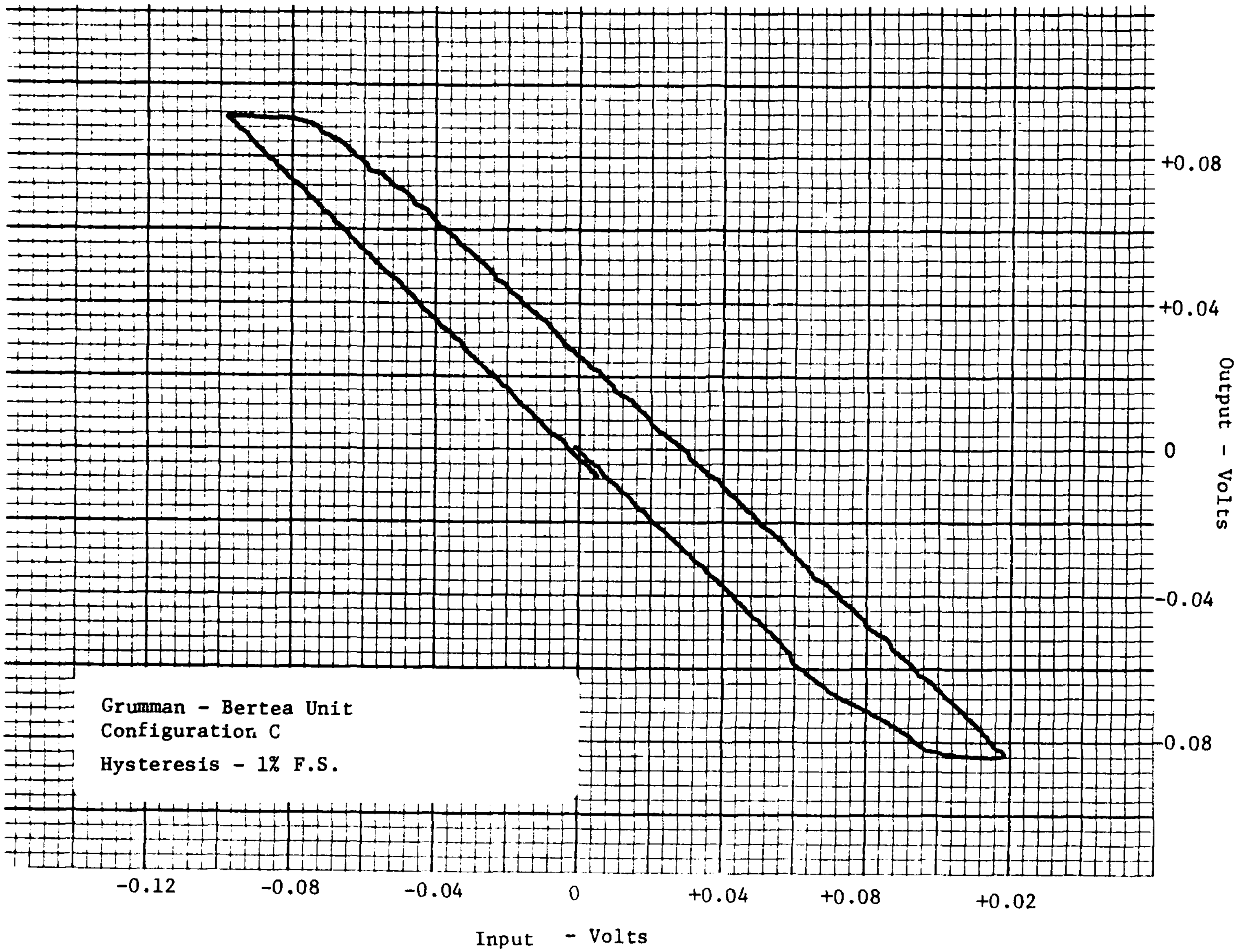



FIGURE 114 Hysteresis - Condition 1

### 3.9.2.5 Hysteresis

Figure 114 shows the data recorded for measuring the hysteresis of Configuration C for Condition 1. The input level used was ±1% of the input for the full actuator position.

Table 24 lists the hysteresis measured for the test Conditions 1 through 11 (Condition 4 omitted) in terms of the actuator full scale input and in terms of the input required to generate full flow from the servovalves.

The hysteresis for Configuration C and the test conditions used was less than that measured on Configuration B and in general greater than that measured on Configuration A. This indicates that the master channel integration technique does reduce the hysteresis of the system with the equalizers connected. This is consistent with the threshold measurements presented previously for Configuration C. Note that the hysteresis in terms of the maximum actuator stroke is less than .22% for all test conditions. When expressed in terms of the maximum unsaturated valve current or stroke, the hysteresis is above 15% for all test conditions and reaches 27% for Condition 11.

It is apparent from the test results that the integration technique does improve the hysteresis measurements compared to using the equalizer without integrating the feedback. Compared to the force sharing mechanization without pressure equalization, the hysteresis is still slightly greater for almost all test conditions.

TABLE 24

Hysteresis

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 4/19/79

TEST ITEM - Grumman - Bertea Unit
Configuration C

TEST - HYSTERESIS

| Test Condition | % Full Scale | % of $E_v$ Max |
|---|---|---|
| 1 | 0.12 | 15.61 |
| 2 | 0.14 | 18.21 |
| 3 | 0.19 | 24.06 |
| 4 | | |
| 5 | 0.18 | 23.41 |
| 6 | 0.19 | 24.71 |
| 7 | 0.19 | 24.71 |
| 8 | 0.19 | 24.71 |
| 9 | 0.17 | 22.11 |
| 10 | 0.16 | 20.81 |
| 11 | 0.21 | 27.31 |

3.9.2.6 Saturation Velocity

Figure 115 shows the data recorded for test Condition 1 in order to determine the saturated velocity of Configuration C. Both the extend and retract time traces of a step input of approximately 10 volts are shown. The input voltage used was large enough to insure that the maximum flow to the actuator was obtained from the servovalves.

Table 25 lists the saturated extend and retract velocities for the test Conditions 1 through 11 ( Condition 4 omitted). The test results indicate negligible change from the values measured for Configurations A and B. This is to be expected since the integration rate was significantly slower than the saturation velocity of the actuator and would not be expected to effect the actuator saturation velocity.

3.9.2.7 Linearity

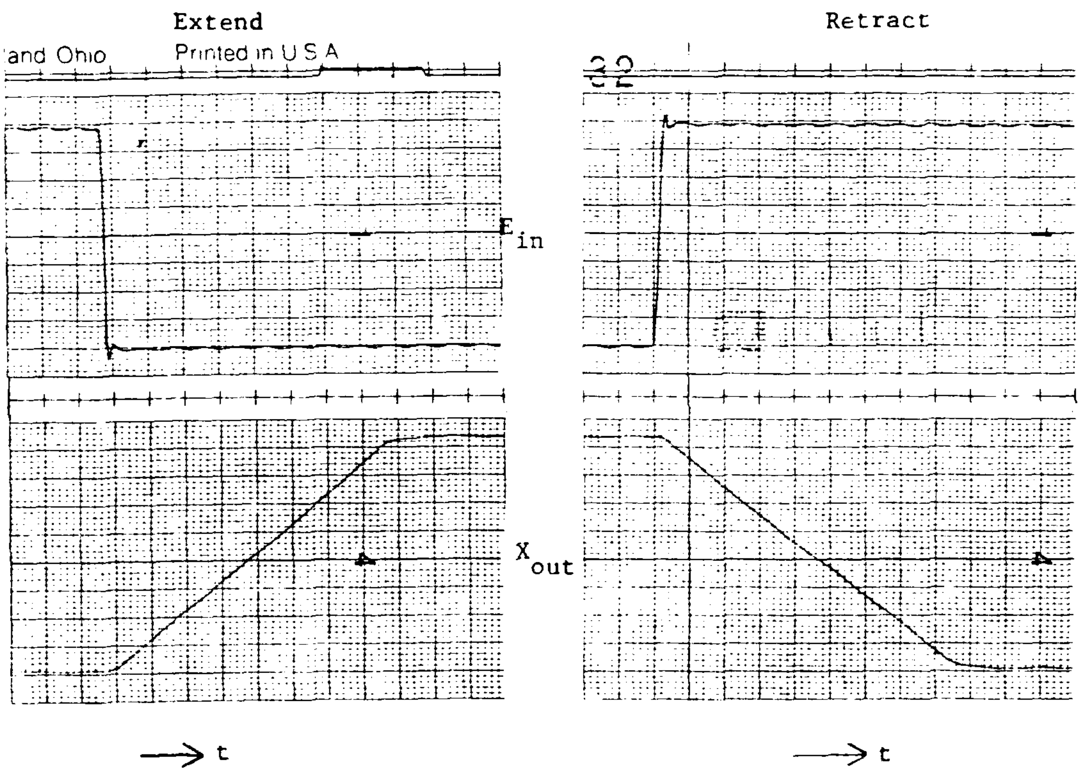
Figure 116 shows the actuator output linearity measured for Configuration C and Condition 1. The output linearity of the mechanization is primarily determined by the position feedback transducer used for the master channel. No change from the linearity of Configurations A and B is apparent. The linearity measured for all operating conditions was essentially the same as that shown on Figure 116 and was within 1% full scale.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date Prepared 4/25/79

TEST - Saturation Velocity - Condition 1




Maximum Amplitude Step Input

Scale: Input = 0.200 v/div

$X_{out}$ = 0.013 in/div

t = 200 div/sec

FIGURE 115 Saturation Velocity - Condition 1

TABLE 25

Saturation Velocity

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 4/19/79

TEST ITEM - Grumman - Bertea Unit
Configuration C

TEST - SATURATION VELOCITY

| Test Condition | Extend - in./sec. | Retract - in./sec. |
|---|---|---|
| 1 | 2.60 | 2.74 |
| 2 | 2.60 | 2.45 |
| 3 | 2.32 | 2.22 |
| 4 | | |
| 5 | 2.00 | 2.14 |
| 6 | 2.81 | 2.60 |
| 7 | 2.60 | 2.74 |
| 8 | 2.54 | 2.74 |
| 9 | 2.74 | 2.67 |
| 10 | 2.48 | 2.60 |
| 11 | 2.43 | 2.45 |

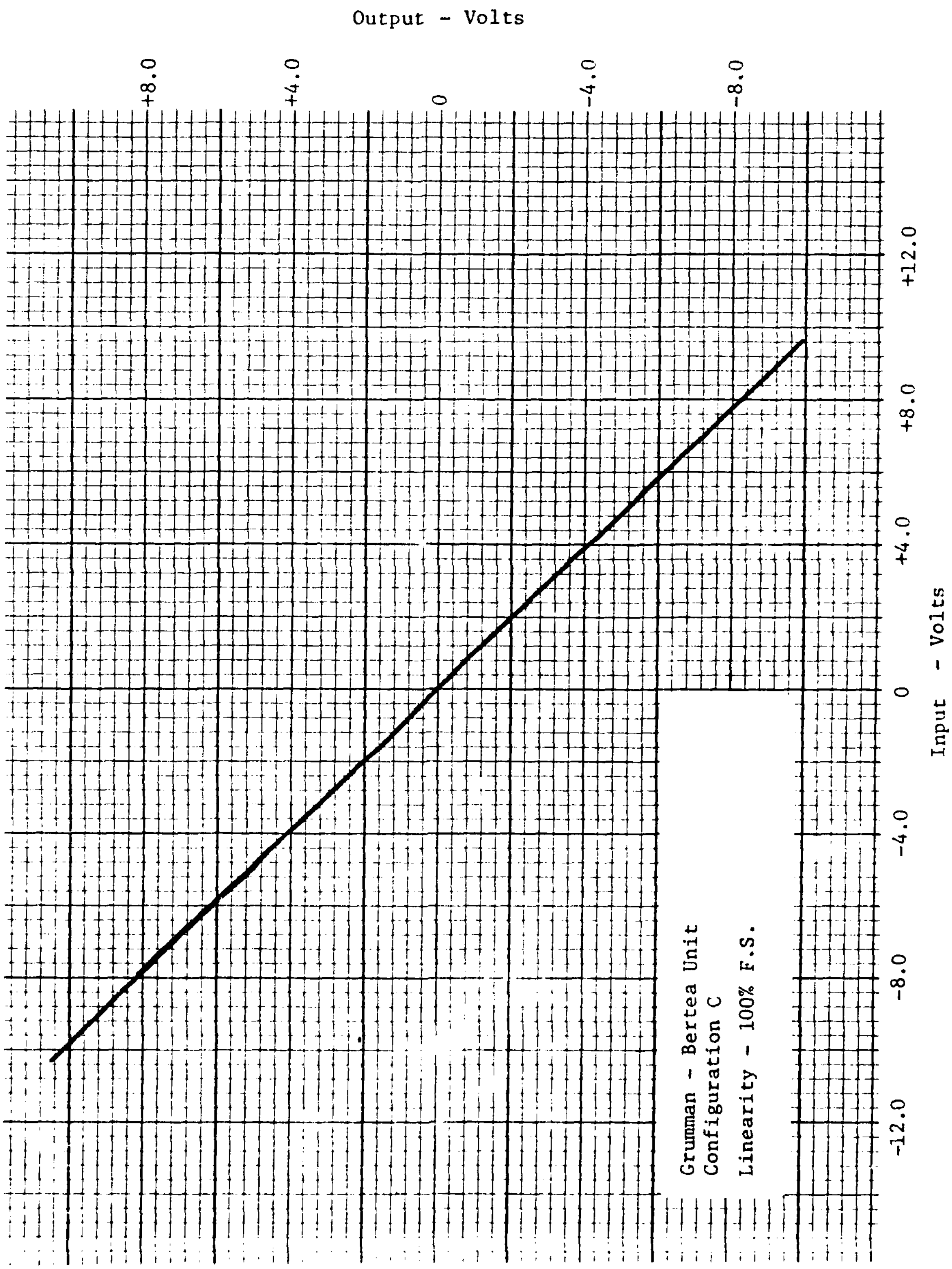



FIGURE 116 Linearity - Condition 1

### 3.9.2.8 Step Response

Figures 117 through 121 show the extend and retract step response measurements for Conditions 1 through 11 (Condition 4 omitted). The input level used for the measurements was large enough to saturate the servovalves until the actuator output moves 50% of the total movement in response to the command step. During the first 50% of the movement, the actuator moved at a saturated rate. The remaining 50% of the movement as shown on Figures 117 through 121 is unsaturated and indicates the transient response of the configuration.

The results indicated by the step response measurements are similar to those measured on both Configurations A and B and are consistent with the frequency response test results for the same test conditions. The integrators used for Configuration C have no apparent effect on the unloaded step response of the mechanization. This is consistent with the relative rates of the actuator and the integrators. The integrators modify the long term position of the control channels while the step response is a relatively short term characteristic.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date
Prepared 4/30/79

TEST - Step Response - Conditions 1 & 2

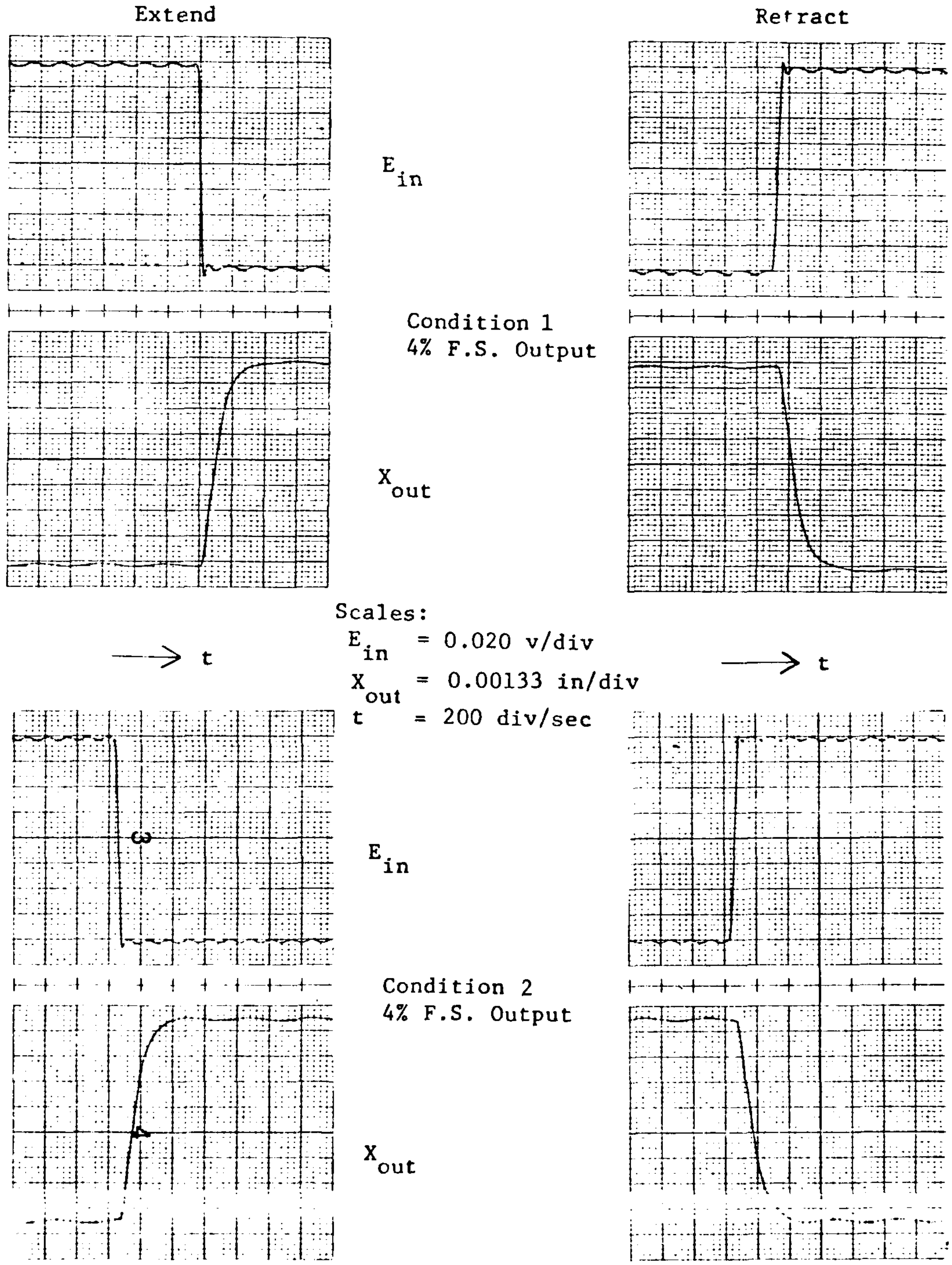



FIGURE 117 Step Response - Conditions 1 & 2

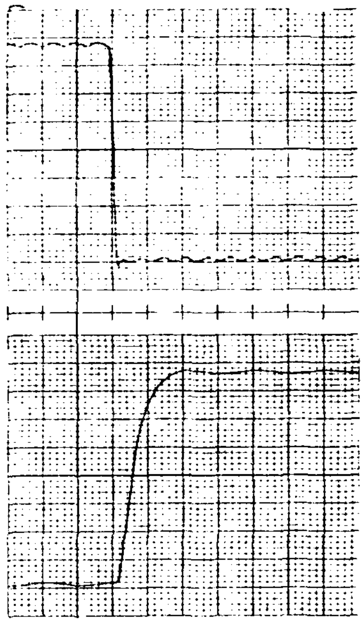
DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

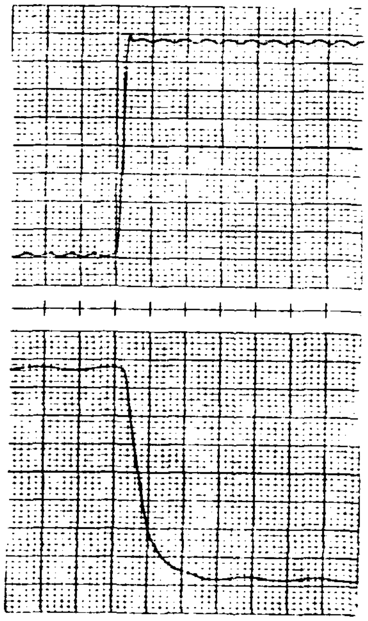
TEST - Step Response - Conditions 3 & 5

Date
Prepared 4/30/79

Extend



Retract



$E_{in}$

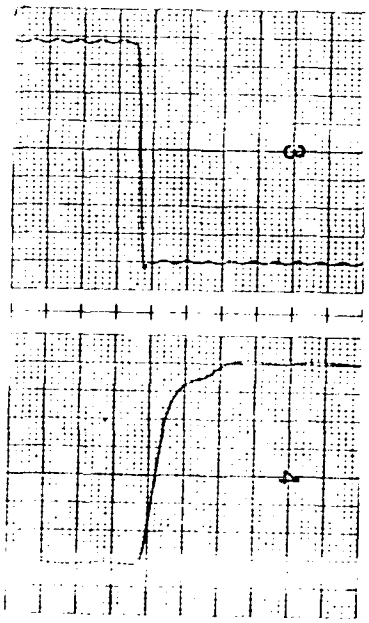
Condition 3
4% F.S. Output

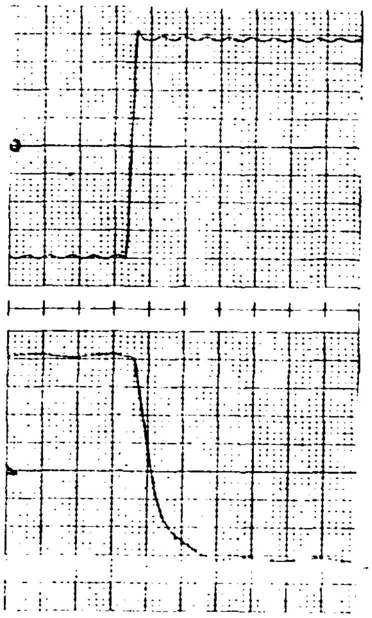
$X_{out}$

Scales:
$E_{in}$ = 0.020 v/div
$X_{out}$ = 0.00133 in/div
t = 200 div/sec

---> t

---> t





$E_{in}$

Condition 5
4% F.S. Output

$X_{out}$

FIGURE 118 Step Response - Conditions 3 & 5

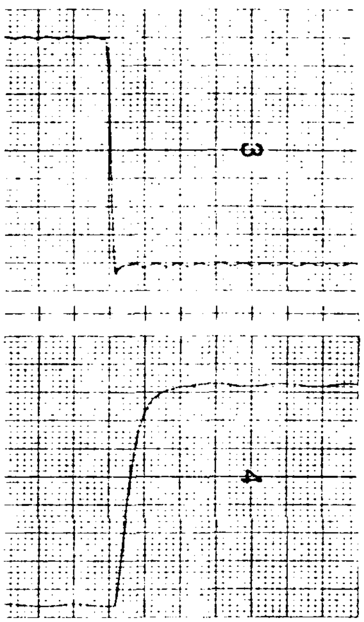
DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

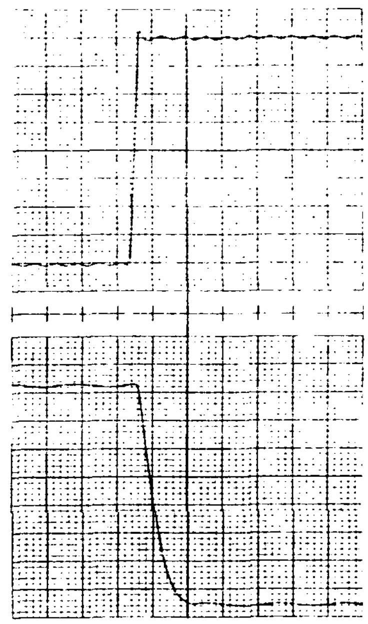
Date
Prepared 4/30/79

TEST - Step Response - Conditions 6 & 7

Extend



Retract



$E_{in}$

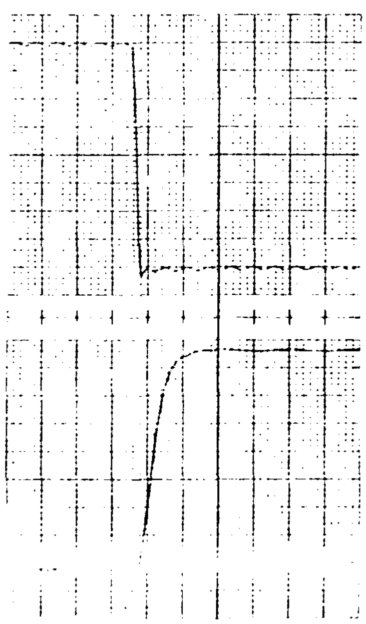
Condition 6
4% F.S. Output

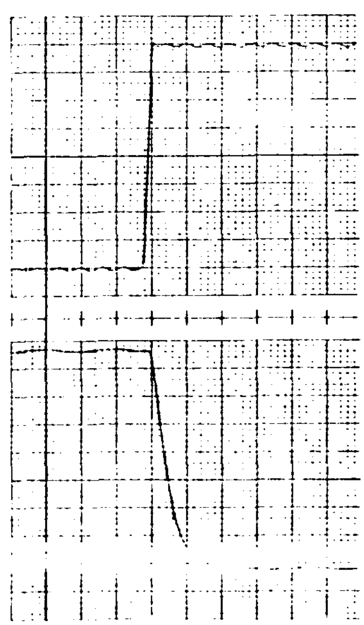
$X_{out}$

→ t

Scales:
$E_{in}$ = 0.020 v/div
t = 0.00133 in/div
$X_{out}$ = 200 div/sec

→ t





$E_{in}$

Condition 7
4% F.S. Output

$X_{out}$

FIGURE 119 Step Response - Conditions 6 & 7

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

TEST - Step Response - Conditions 8 & 9

Date Prepared 4/30/79

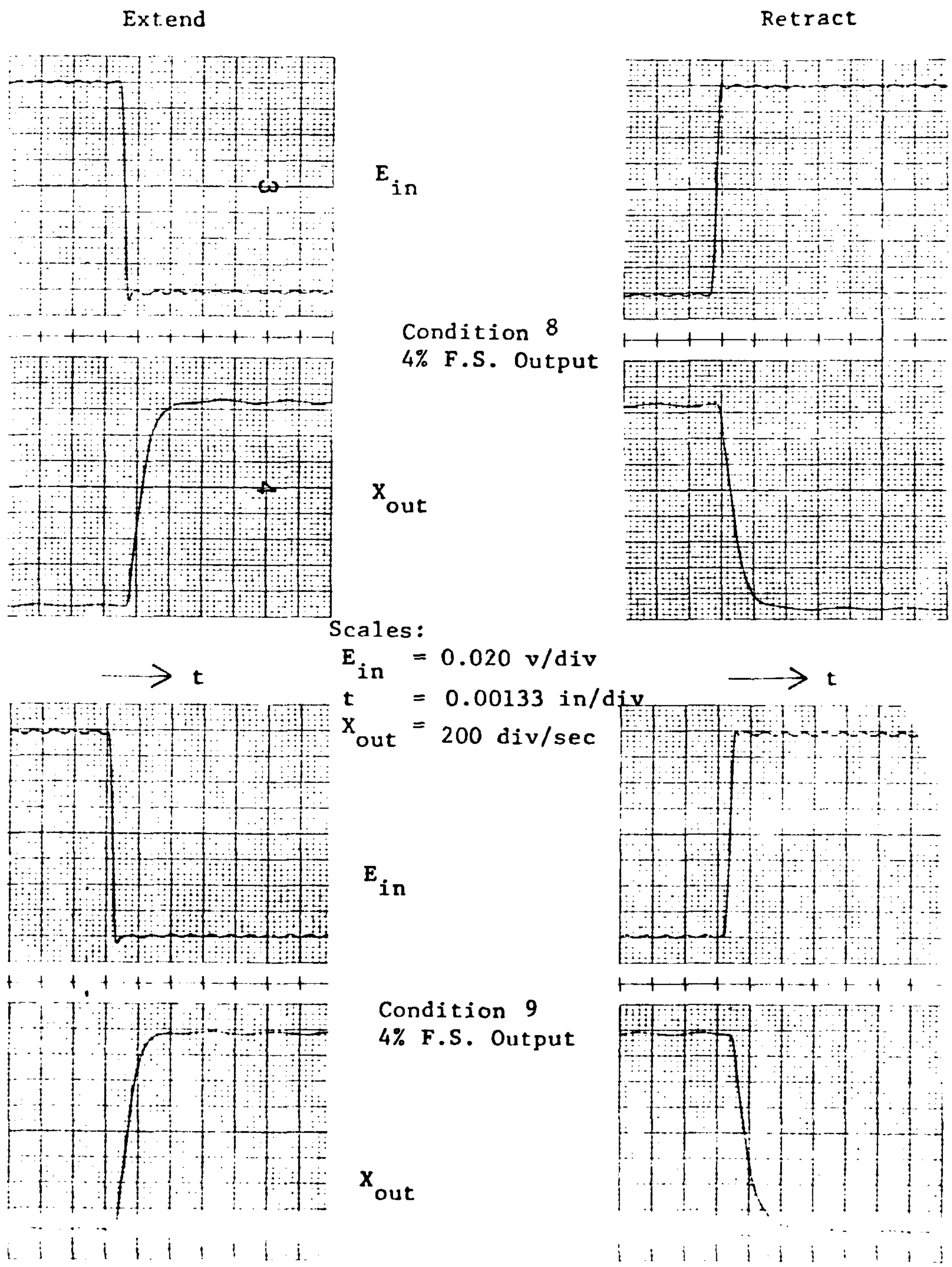



FIGURE 120 Step Response - Conditions 8 & 9

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

TEST - Step Response - Conditions 10 & 11

Date Prepared 4/30/79

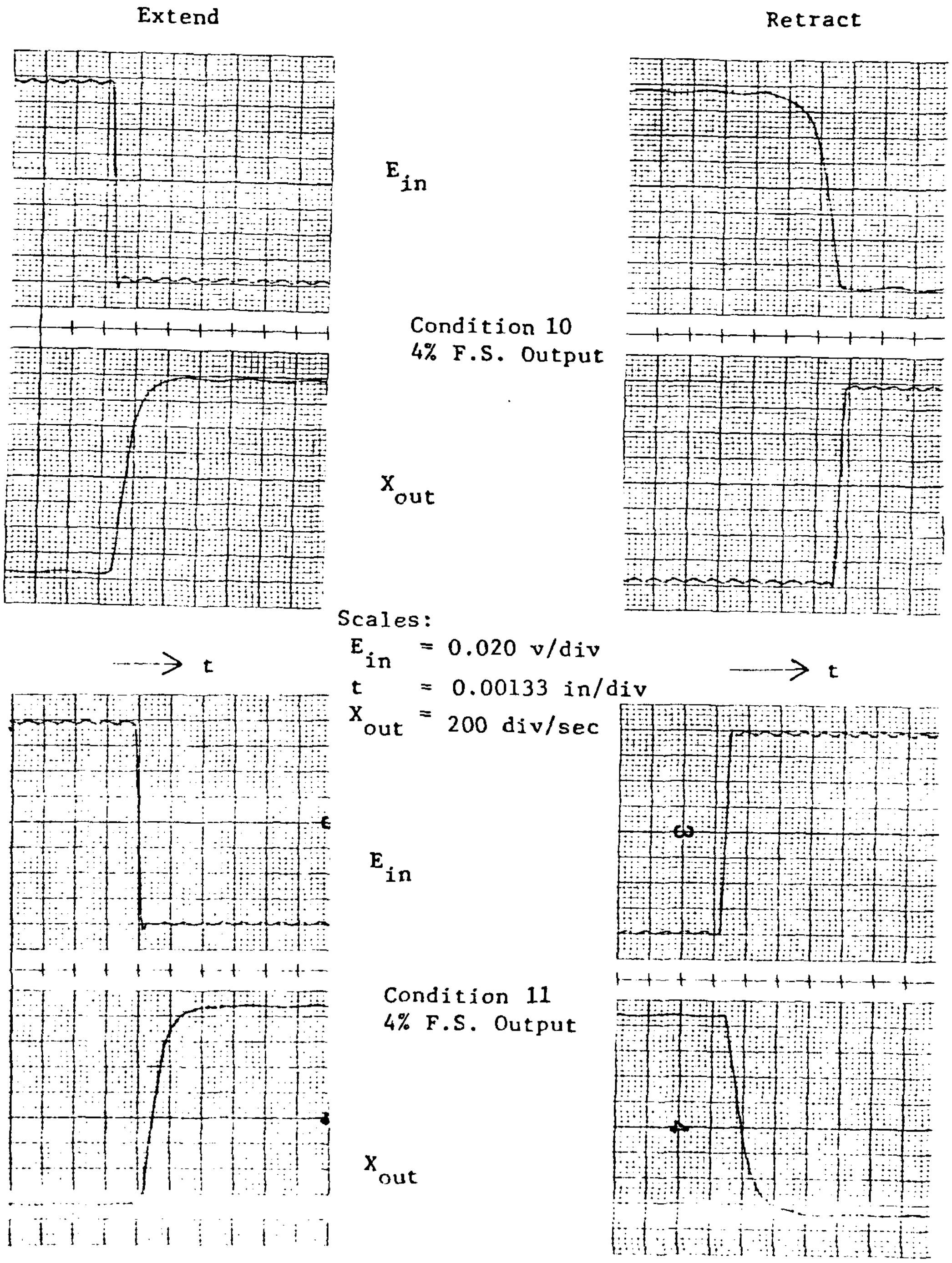



FIGURE 121 Step Response - Conditions 10 & 11

### 3.9.3 Failure Transients

Test Conditions 12 through 27 were used to establish the failure transient characteristics of Configuration C. The test results and the test conditions are arranged in the following order:

| TEST | Test Conditions |
|---|---|
| Electrical Input Loss Transient | 12 13, 14, 15 |
| Electrical Hardover Input Transient (with actuator initially at rest) | 16, 17, 18, 19, 20, 21 |
| Electrical Hardover Input Transient (with actuator initially cycling) | 22, 23 |
| Simultaneous Hardover Input Transient | 24, 25 |
| Slowover Electrical Input Transient | 26, 27 |

The test results in the following sub-sections are presented as listed above.

#### 3.9.3.1 Electrical Input Loss Transient

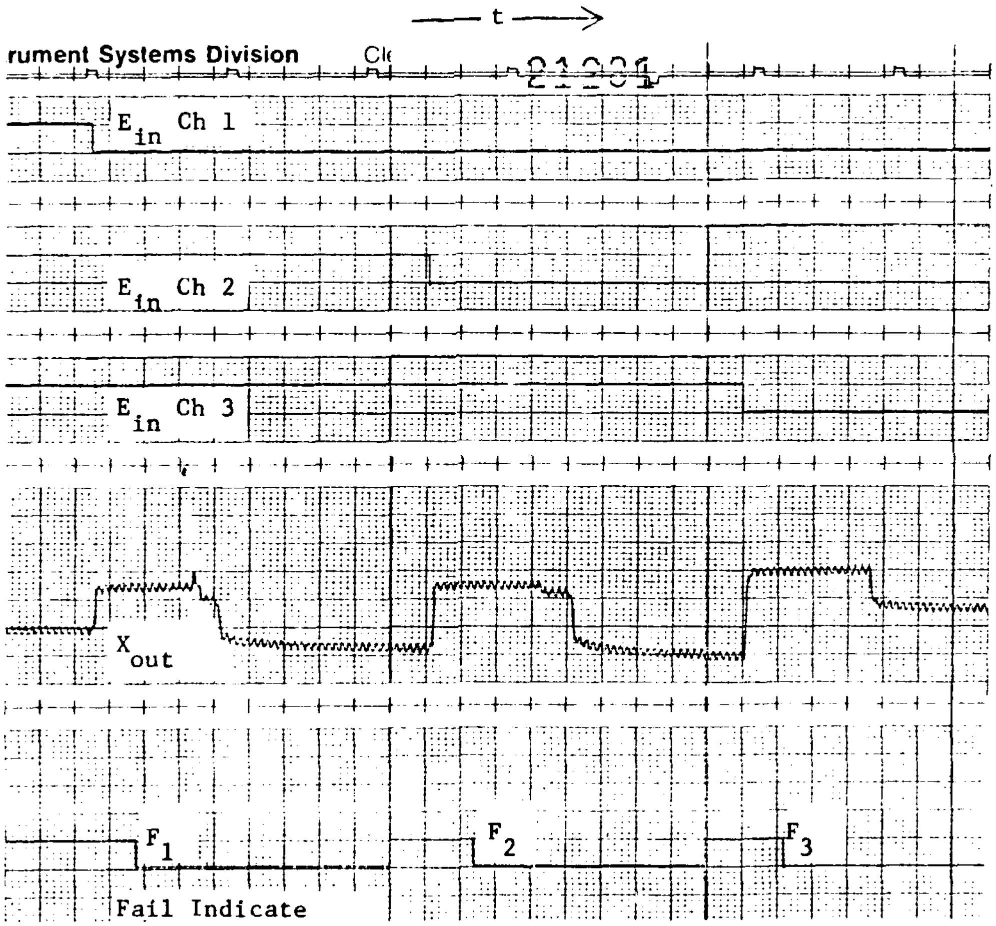
Figures 122 and 123 show the effect of a sequential channel input loss with the actuator initially commanded to a 50% of maximum position away from null. Figure 122 is the failure transient for the extend bias position. The output deviation for the first failure is .71% of the total actuator stroke. After depressurization of channel 1 (the master channel) and changing of the force limit of channel 4 to 100%, the null offset of the system output is .23% of the total actuator stroke. This initial deviation is larger than that measured for Configurations A and B for the same test condition. Configuration A incurred a .32% deviation and Configuration B incurred a .63% deviation.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date Prepared 6/11/79

TEST - Failure Transients - Condition 12




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.0013 in/div
t = 20 div/sec

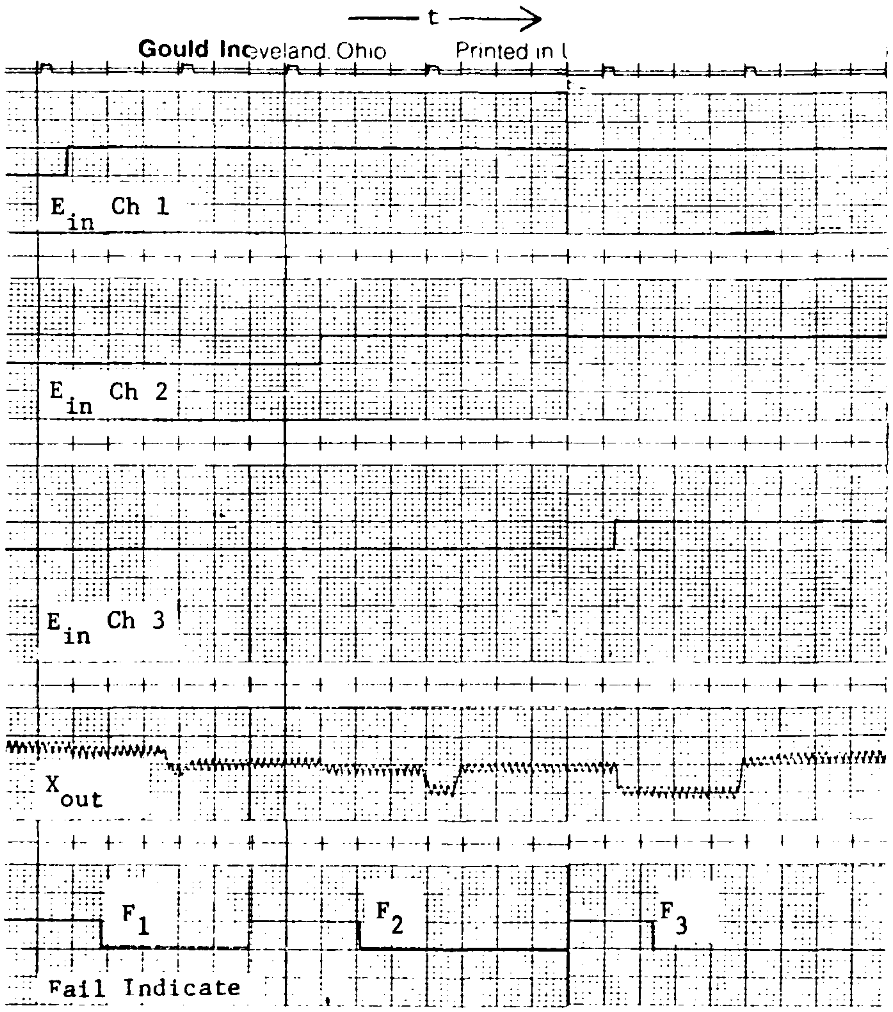
FIGURE 122 Failure Transients - Condition 12

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date
Prepared 6/11/79

TEST - Failure Transients - Condition 13




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.0013 in/div
t = 20 div/sec

FIGURE 123 Failure Transients - Condition 13

The output deviation for the second failure (channel 2) is 1.20% of the total actuator stroke. After depressurization of channel 2 and the transfer of the master channel role to channel 3, the null offset of the system is .10% of the total actuator stroke. As with the first failure, the failure transient is larger than that encountered with Configuration A and B. Configuration A incurred a .32% deviation and Configuration B incurred a .81% deviation. The deviation of the actuator upon a third failure for Configuration C is 1.50% of the total actuator stroke. The comparable deviation of Configuration A was .68% and of Configuration B was .92%. As with Configuration A and B, the Configuration C failure logic arbitrarily selected channel 3 (the channel with the input loss) for depressurization as a failed channel. The transient measured for the third failure is the deviation of the system output before depressurization of channel 3 and represents the deviation which would occur if the failure logic was prevented from the third channel depressurization. This approach to the failure logic (no depressurization after 2 failures) would prevent the hardover output that would occur if the logic depressurized arbitrarily the channel with a "good" input.

Figure 123 shows the effect of the sequential channel input loss with the actuator commanded to a 50% maximum retract stroke. The output transient for the first failure is .35% of the total actuator stroke. This compares favorably with the .32% deviation of Configuration A and the .65% deviation for Configuration B. The output deviation for the second input loss failure is .35% of the maximum actuator stroke. This is similar to the .32% deviation for Configuration A and the .30% deviation measured with Configuration B.

The output deviation for the third input failure is .45% of the full actuator stroke. This is less than the deviation of .79% measured for Configuration A and .75% measured for Configuration B and the same test condition.

The deviation experienced with Configuration C for some test conditions was expected to be somewhat greater than that of Configuration A and B for some test conditions. The test results measured for the input loss failures with the initial extend positions agreed with the anticipated results.

Figure 124 shows the effect of sequentially grounding the inputs to channels 1, 2 and 3 with the system operating at a frequency of 10 Hz at a maximum unsaturated input amplitude. At this operating condition, the failure logic does not detect a failure and depressurize the failed channel. The failure logic does not pass the 10 Hz signal to the voting portion of the logic. Therefore, the failure logic does not see loss of the 10 Hz input signal as a failure. The test results for this failure condition are similar to that experienced with Configurations A and B. The net effect of the failures is that the output amplitude of the system decreases with each additional failure. This is because the control channels with the grounded inputs fight the channels with the 10 Hz input commands.

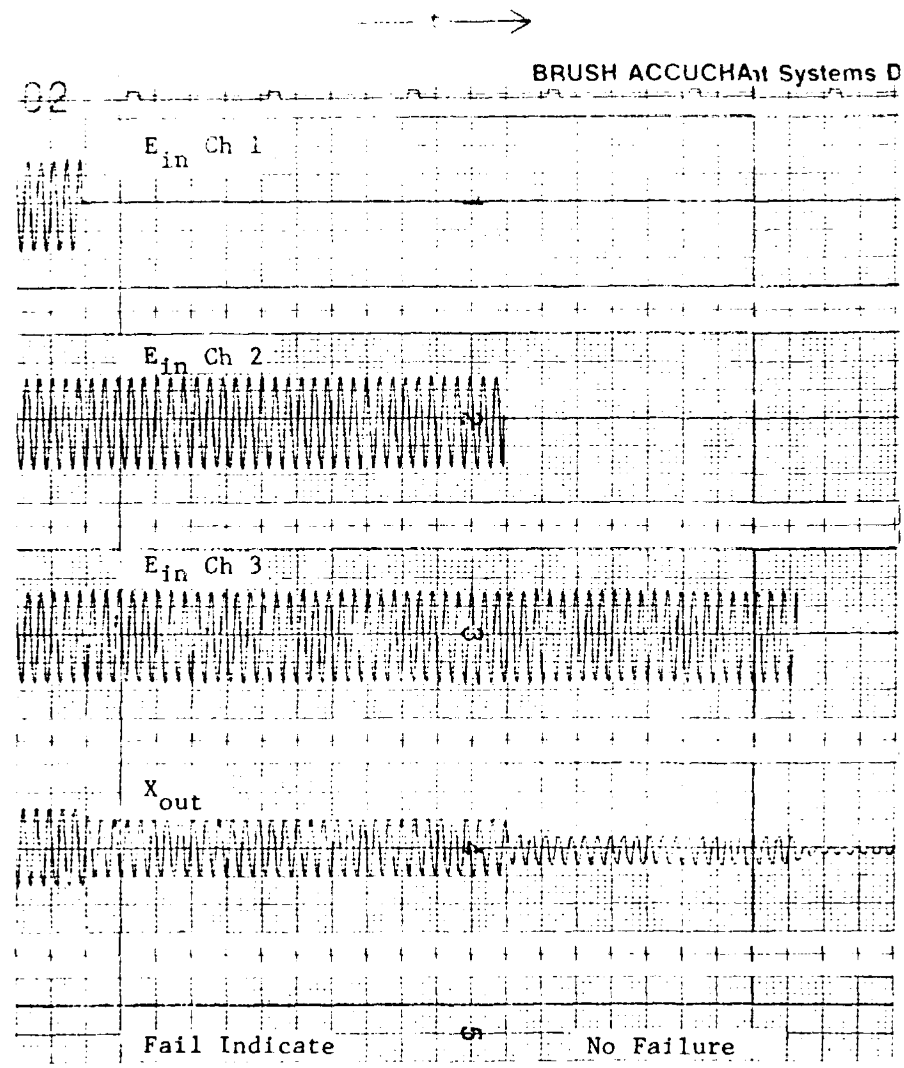
The addition of the integrators was not expected to effect the test results for this test condition. The measured results agree with the anticipated results.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date
Prepared 6/12/79

TEST - Failure Transients - Condition 14




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.0033 in/div
t = 20 div/sec

FIGURE 124 Failure Transients - Condition 14

Figure 125 shows the effect of simultaneous grounding of two input channels with the actuator cycling at 10 Hz at an amplitude of ± 1.6% of the maximum actuator stroke. The failures are not detected and the output amplitude of the actuator is reduced to 38% of the "no failure" amplitude. The failure logic does not sense the failed condition, so the four channels simply force sum. The channels with grounded inputs fight the channels with the 10 Hz input. This result is the same as encountered with Configuration A. This test was not conducted on Configuration B.

3.9.3.2 Hardover Input Transient

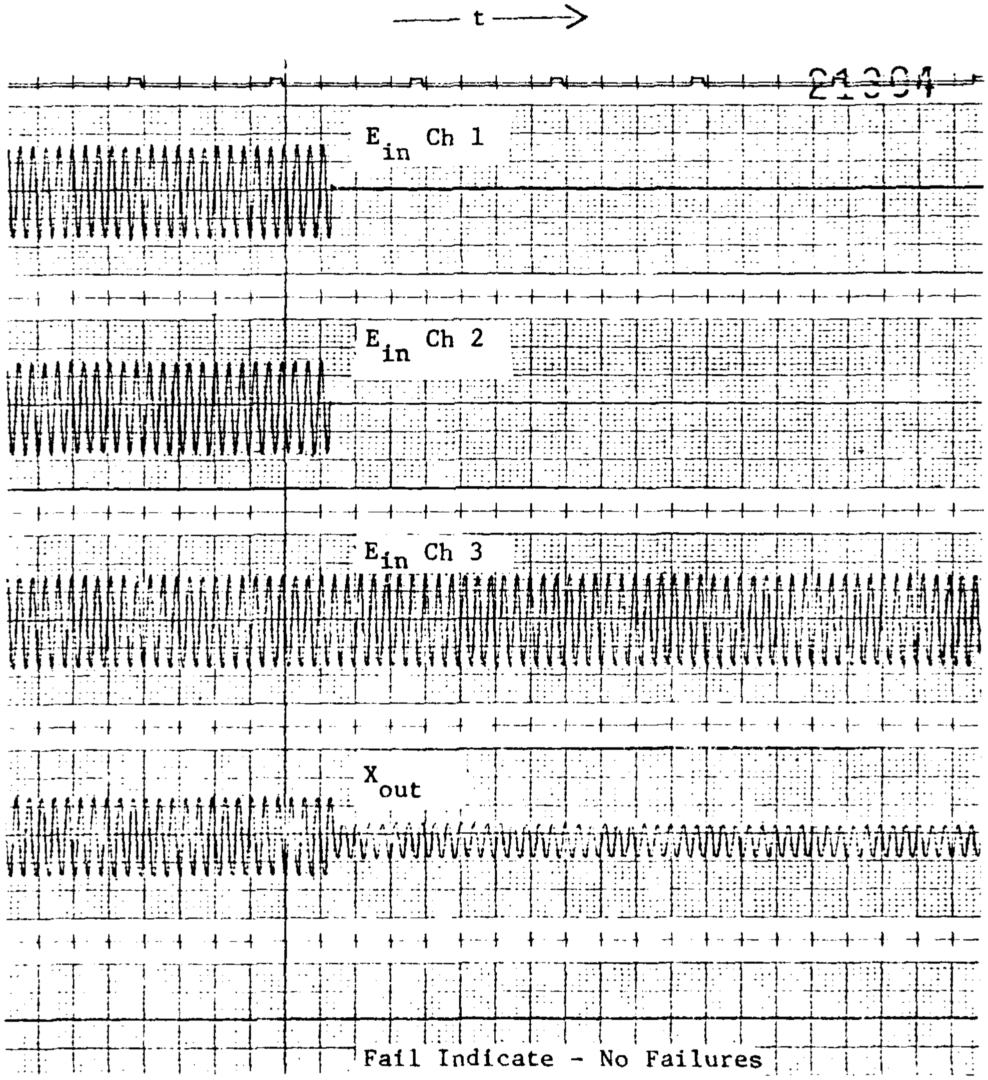
Figure 126 shows the effect of a positive 10 volt step applied sequentially to channels 1, 2 and 3. The failure logic detects the failures and at approximately .85 seconds after each hardover the system output establishes a new position. The output deviation resulting from the first hardover channel input is a steady state null offset which is .5% of the total actuator stroke. This is larger than the .45% deviation for Configuration B and similar to the .58% deviation for Configuration A. The second hardover input into channel 2 produces an output deviation of .5% of the total actuator stroke. This is less than the .58% deviation of Configuration A and more than the .3% deviation of Configuration B. The third hardover input (into channel 3) produces an output deviation of .4% of the maximum actuator stroke. This is less than the .65% deviation of Configuration B and the .79% deviation of Configuration A.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date
Prepared 6/12/79

TEST - Failure Transients - Condition 15




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.0033 in/div
t = 20 div/sec

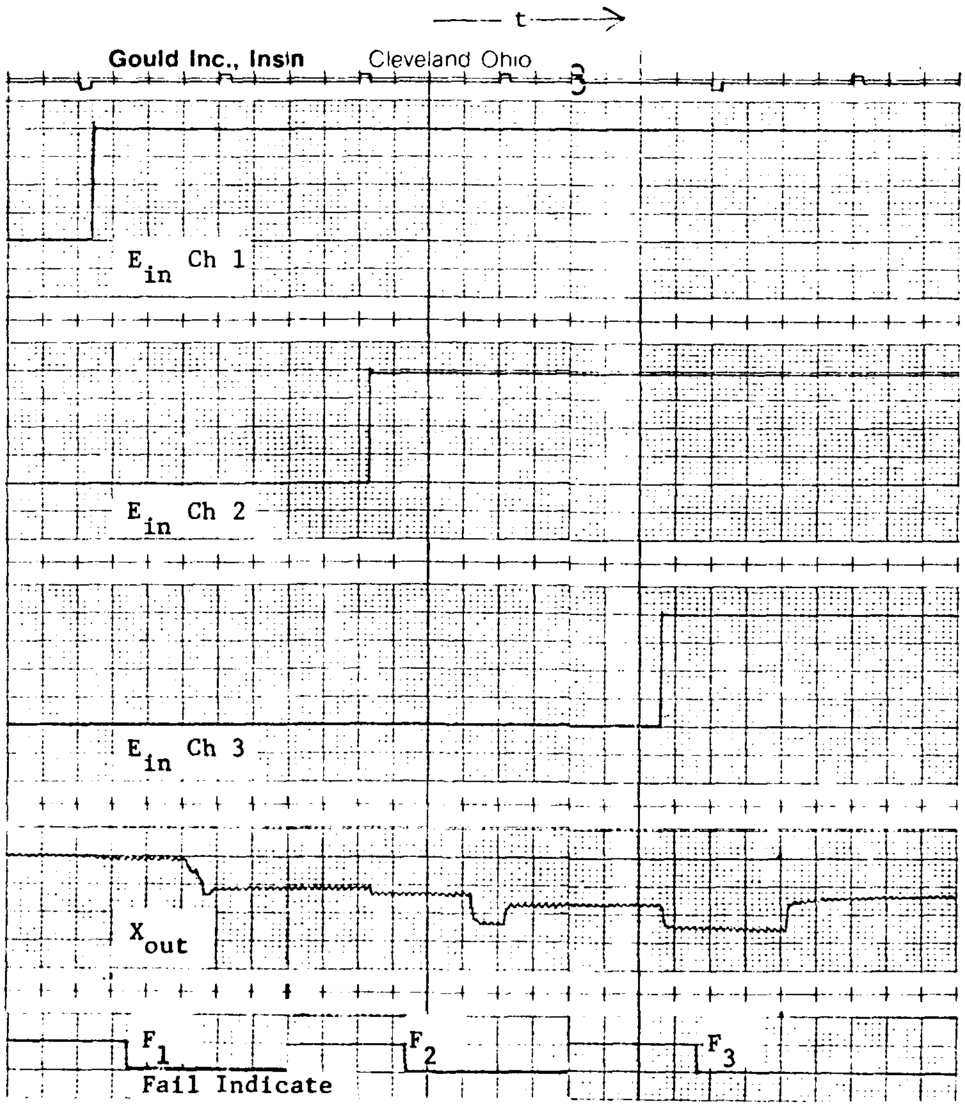
FIGURE 125 Failure Transients - Condition 15

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date
Prepared 6/8/79

TEST - Failure Transients - Condition 16




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.0013 in/div
t = 20 div/sec

FIGURE 126 Failure Transients - Condition 16

Figure 127 shows the actuator deviations for a negative 10 volt input sequentially applied to channel 1, 2 and 3 inputs. The actuator deviation for the first hardover input into channel 1 causes an output position change of .97% of the total actuator stroke. As with the positive hardover input failures, the failure is detected after approximately .85 seconds and channel 1 depressurized and the master channel role moved to channel 2. This deviation is greater than the .6% deviation measured on Configuration B and the .37% deviation measured on Configuration A.

The second input hardover into channel 2 causes an output deviation of 1.10% of the maximum actuator stroke. This is greater than the output deviation of 1.0% for Configuration B and the .79% output deviation for Configuration A. The third hardover input into channel 3 causes an output deviation of 1.50% of the total actuator stroke. Again this is larger than the .79% deviation for Configuration A and the 1.0% deviation of Configuration B.

The hardover input failures cause slightly greater output deviation for Configuration C than either Configuration A or B. This is probably due to the operating point of the integrating channels requiring slightly greater output changes for force balancing than with Configuration A and B.

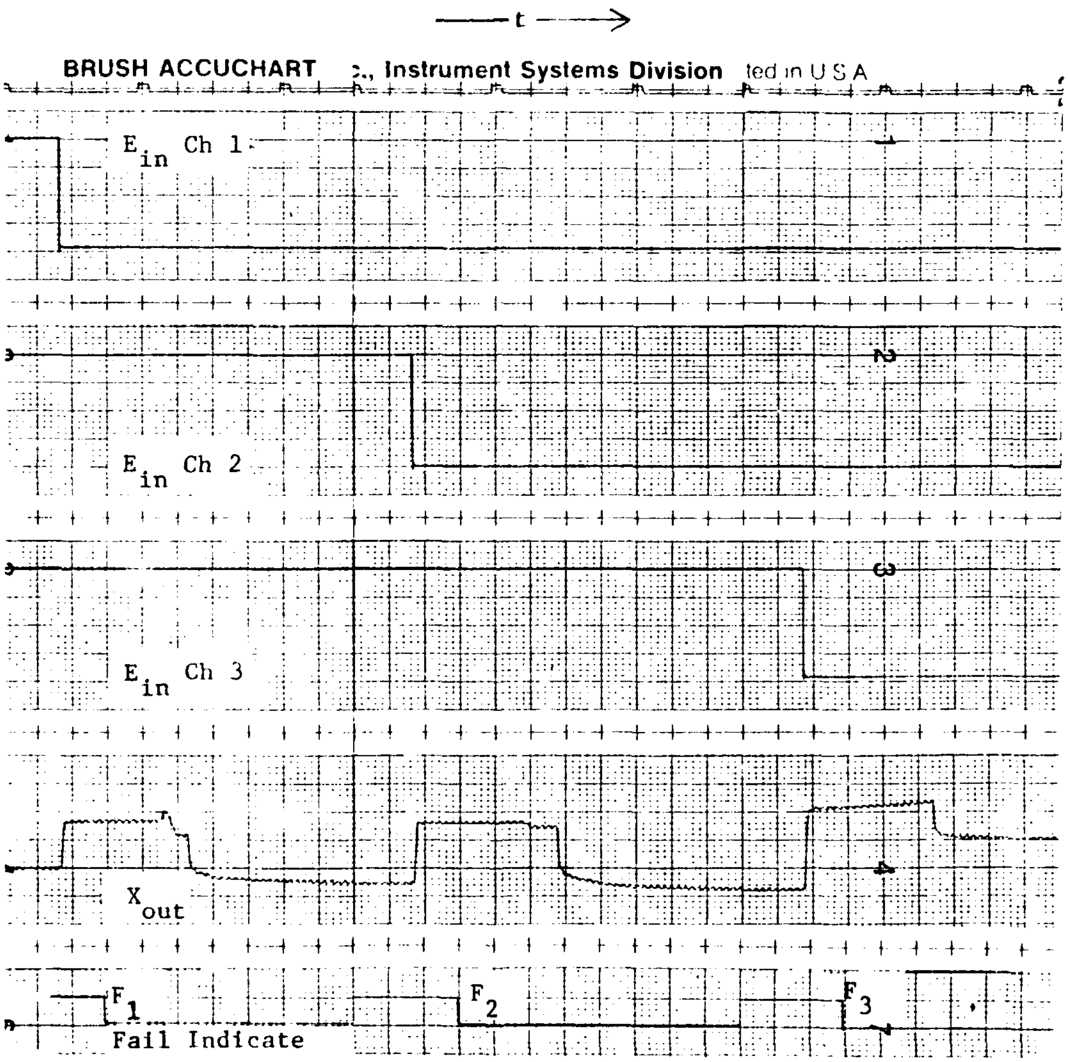
Figure 128 shows the actuator deviations for a hardover input of +10 volts sequentially applied to channels 1, 2 and 3 with the system initially biased to a 50% extend position. The actuator output deviation for the first hardover input into channel 1 is .61% of the total actuator stroke. The null offset after this particular hardover input is .55% of the total actuator stroke and reflects the change in the force balance position before and after the input failure applied and detected as a failure. The deviation itself is somewhat larger than the .42% of Configuration A and .4% of Configuration B for the same test condition.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date
Prepared 6/8/79

TEST - Failure Transients - Condition 17




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.0013 in/div
t = 20 div/sec

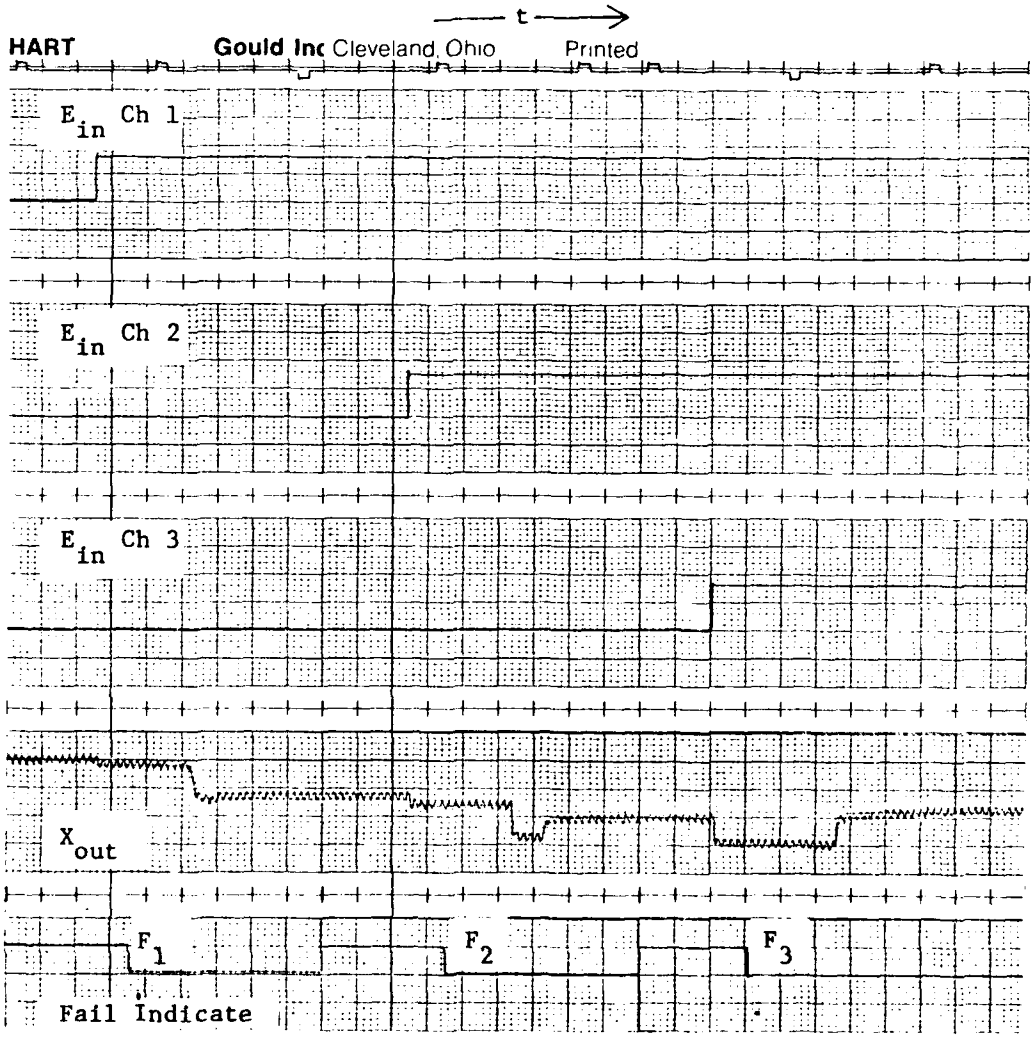
FIGURE 127 Failure Transients - Condition 17

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date Prepared 6/8/79

TEST - Failure Transients - Condition 18




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.0013 in/div
t = 20 div/sec

FIGURE 128 Failure Transients - Condition 18

The deviation with the channel 2 hardover input is .55% of the maximum actuator stroke and compares favorably with the .4% for Configuration A and .5% for Configuration B. The third hardover input failure into channel 3 produces an output deviation of .43% which is less than the .79% of Configuration A and 1.0% of Configuration B.

Figure 129 shows the actuator deviations for a hardover input of -10 volts sequentially applied to channels 1, 2 and 3 with the system biased to a 50% extend position. The actuator output deviation with the first failure input into channel 1 is .79% of the total actuator stroke. This is greater than the .4% of Configuration A and the same as the .7% deviation of Configuration B. The second input failure produced an output deviation of 1.15% of the total actuator stroke which is considerably greater than the .6% deviation measured previously on Configuration A and B. The third input failure into channel three produced an output deviation of 1.53%. The same test conditions for Configuration A and B produced a deviation of .58 and 1.1% respectively.

As with the previous hardover input tests, the use of the integration for the equalizers produces greater output deviations of the system upon hardover input failures than the system with the equalizer alone or disconnected. The magnitude of the output deviation is not affected by the input bias required to extend the actuator output to 50% of the maximum stroke.

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Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

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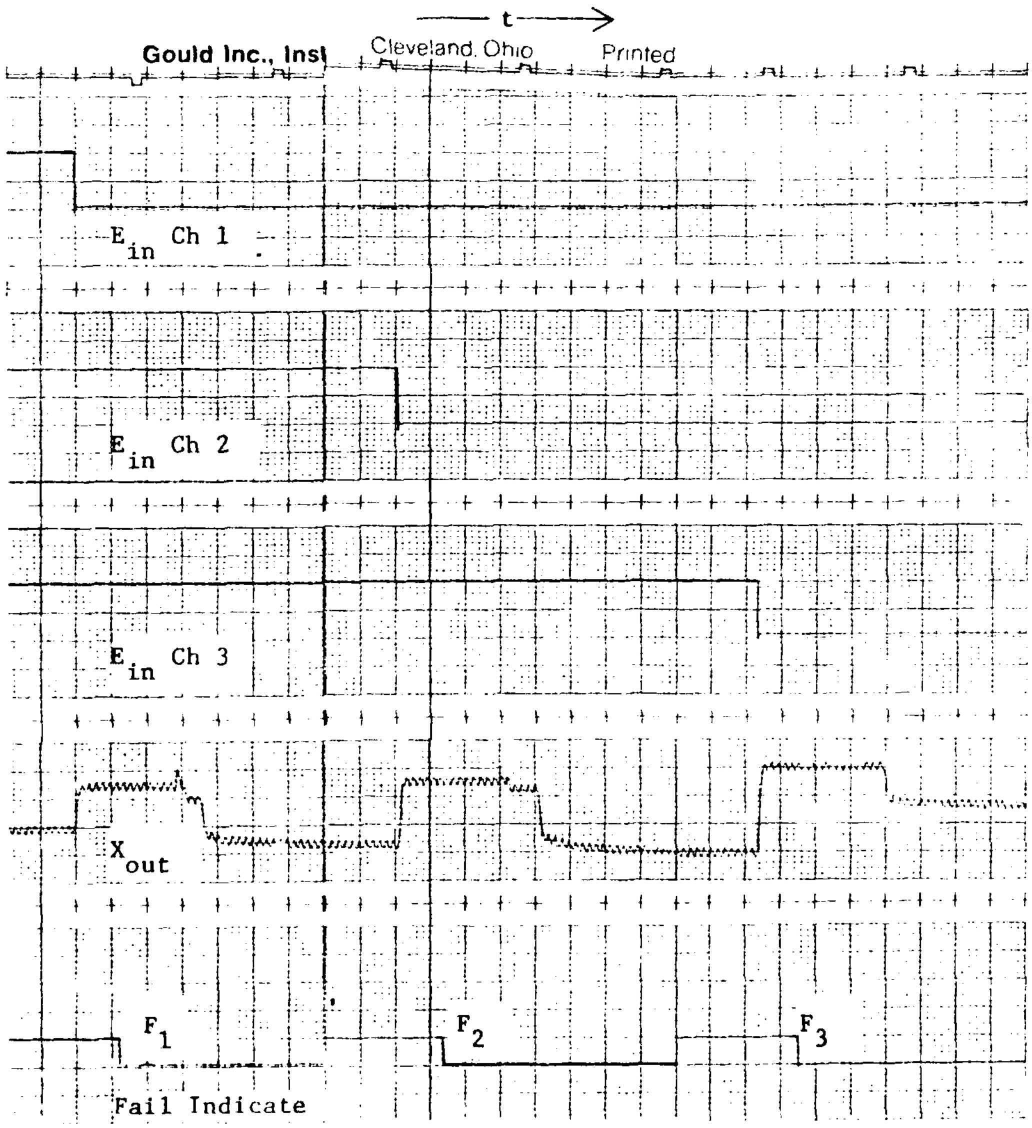
TEST - Failure Transients - Condition 19




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.0013 in/div
t = 20 div/sec

FIGURE 129 Failure Transients - Condition 19

Figure 130 shows the output deviation of Configuration C with a + 10 volt hardover input sequentially applied to channels 1, 2 and 3 with the system biased to a 50% retract position. The output deviation for the first failure input into channel 1 is .40% of the maximum actuator stroke. This is less than the .79% measured on Configuration B and more than the .32% measured on Configuration B and more than the .32% measured on Configuration A. The second hardover input failure into channel 2 produced an output deviation of .35% of the full actuator output stroke. This is comparable to the .3% measured on both Configuration A and B. The third input failure into channel three produced an output deviation of .45% which is less than the .7% measured for Configuration A and greater than the .4% deviation measured on Configuration B.

Figure 131 shows the effects of the sequential application of a - 10 volt input applied to channels 1, 2 and 3 with the system biased to a 50% retract position. The output deviations are larger than that measured for the same bias condition and a + 10 volt hardover input. For the first input failure, the output deviation is 1.09% of the maximum actuator stroke. This is considerably greater than the .47% measured on Configuration A and the .79% measured on Configuration B. The second input failure produced an output deviation of 1.30% of the maximum actuator stroke. This is comparable to the 1.2% deviation measured on Configuration B and larger than the .63% measured on Configuration A. The output deviation of 1.65% for Configuration C with the third failure is less than the 2% deviation measured on Configuration B and greater than the .58% deviation measured on Configuration A.

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Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

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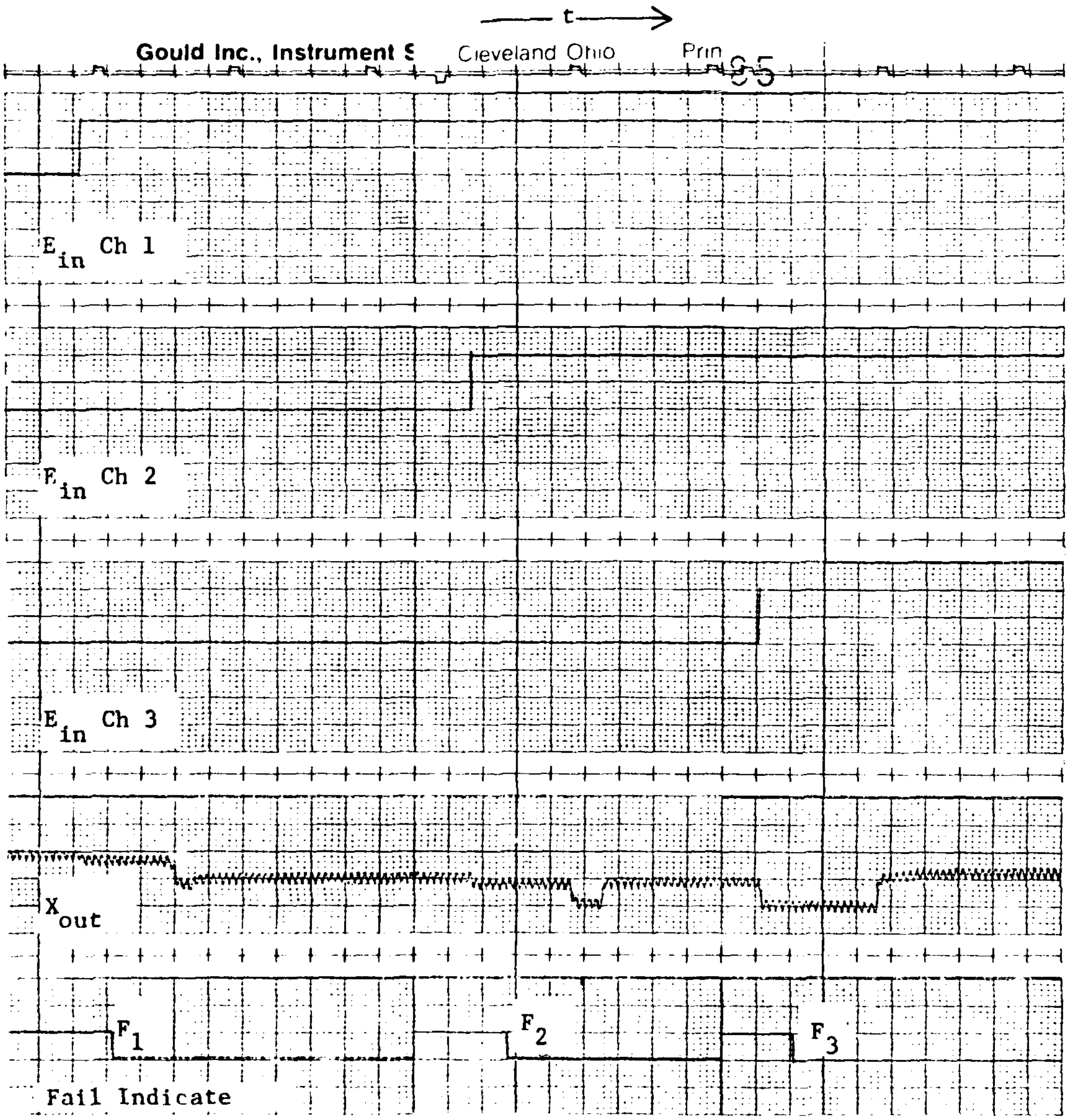
Prepared 6/11/79

TEST - Failure Transients - Condition 20




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.0013 in/div
t = 20 div/sec

FIGURE 130 Failure Transients - Condition 20

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Test Data

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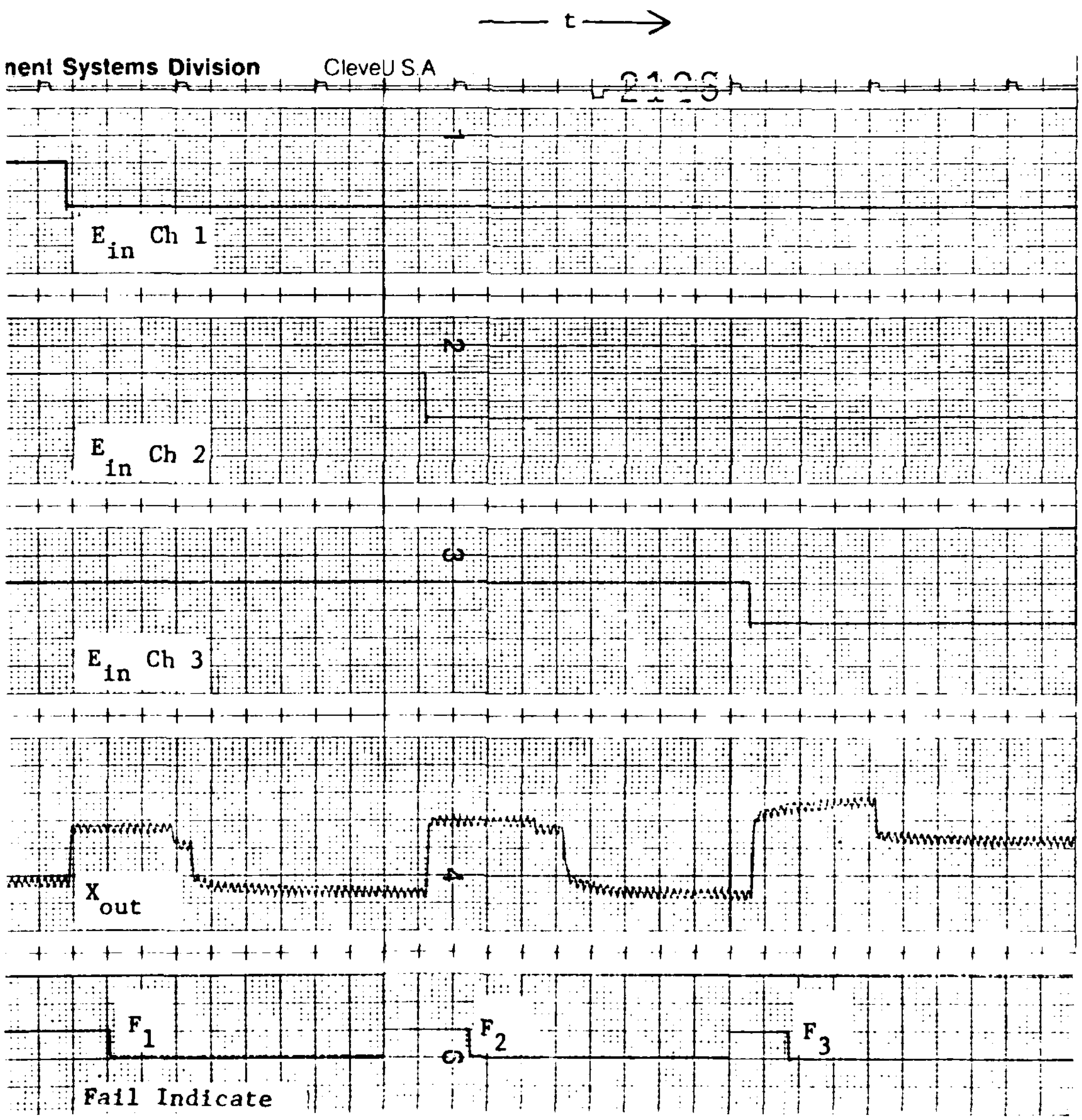
TEST - Failure Transients - Condition 21




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.0013 in/div
t = 20 div/sec

FIGURE 131 Failure Transients - Condition 21

Figures 132 and 133 show the effect on the system output of + 10 volt and - 10 volt hardover inputs sequentially applied to channels 1, 2 and 3 with the system operating at 10 Hz with the maximum unsaturated amplitude. Figure 132 shows the effect of the + 10 volt hardover inputs and Figure 133 shows the effect of the - 10 volt inputs. In both cases the hardover failures are detected and the channel with the failure depressurized. The effect on the system output is a null shift with each failure. For the third failure input into channel 3, the + 10 volt input causes a loss of the 10 Hz output for .85 seconds and then the actuator output continues. For the - 10 volt 3rd failure input into channel 3, the actuator output deviates 4.7% of the maximum actuator stroke and does not respond to the 10 Hz input. The operation of the system with a third failure is of minor interest only, since the system is designed to continue to operate only after two failures, not three.

The test results shown on Figure 132 and 133 are similar to those measured on Configuration A and B. The operation of the integrators on the equalizer outputs does not affect the operation of the system for this test condition as compared to the system with the equalizers only or with the equalizers disconnected.

#### 3.9.3.3 Simultaneous Hardover Input Failure Transient

Figure 134 shows the effect of hardover inputs applied simultaneously to channels 1 and 2 with the system at null. The effect of the hardover inputs is to cause the output of the system to move to a position 10.04% of the maximum actuator stroke away from the null position. The failure logic activates but does not latch. The

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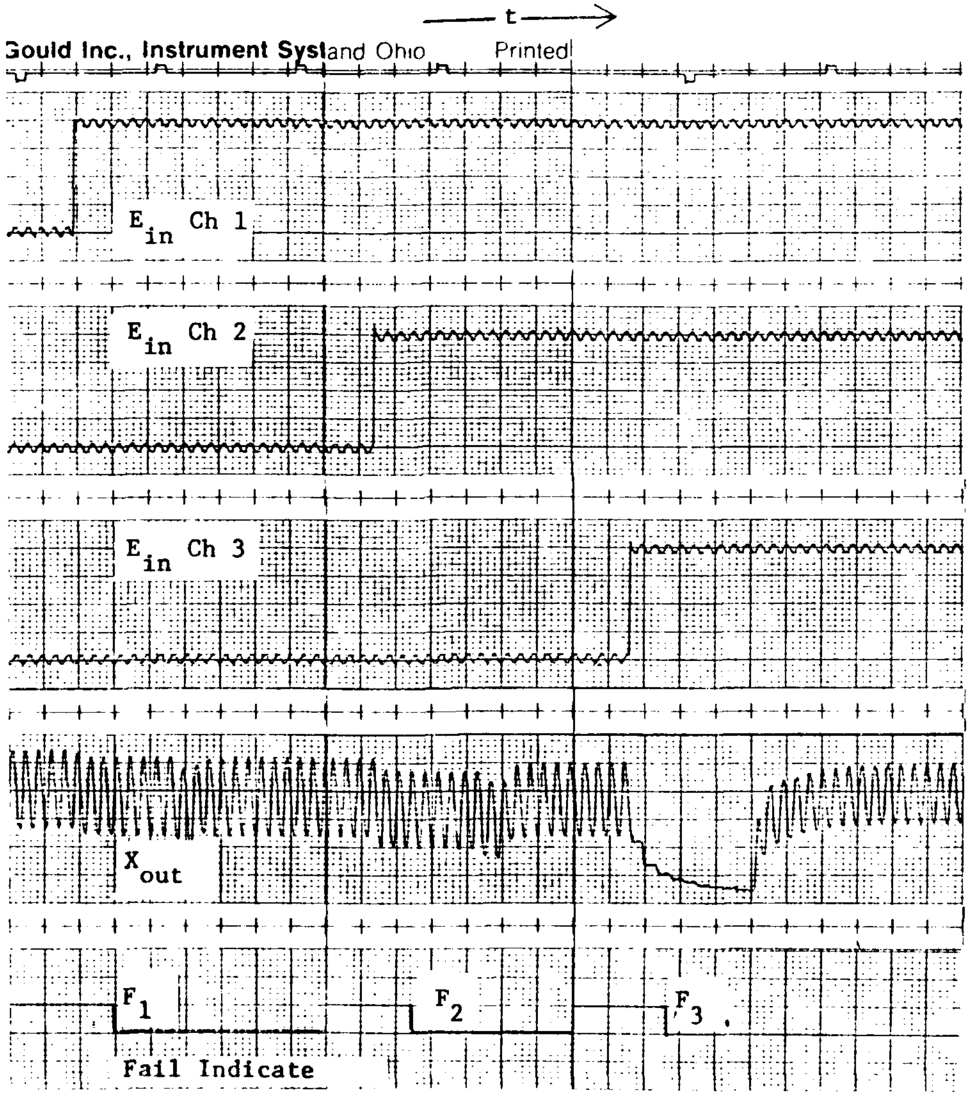
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date
Prepared 6/11/79

TEST - Failure Transients - Condition 22




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.0033 in/div
t = 20 div/sec

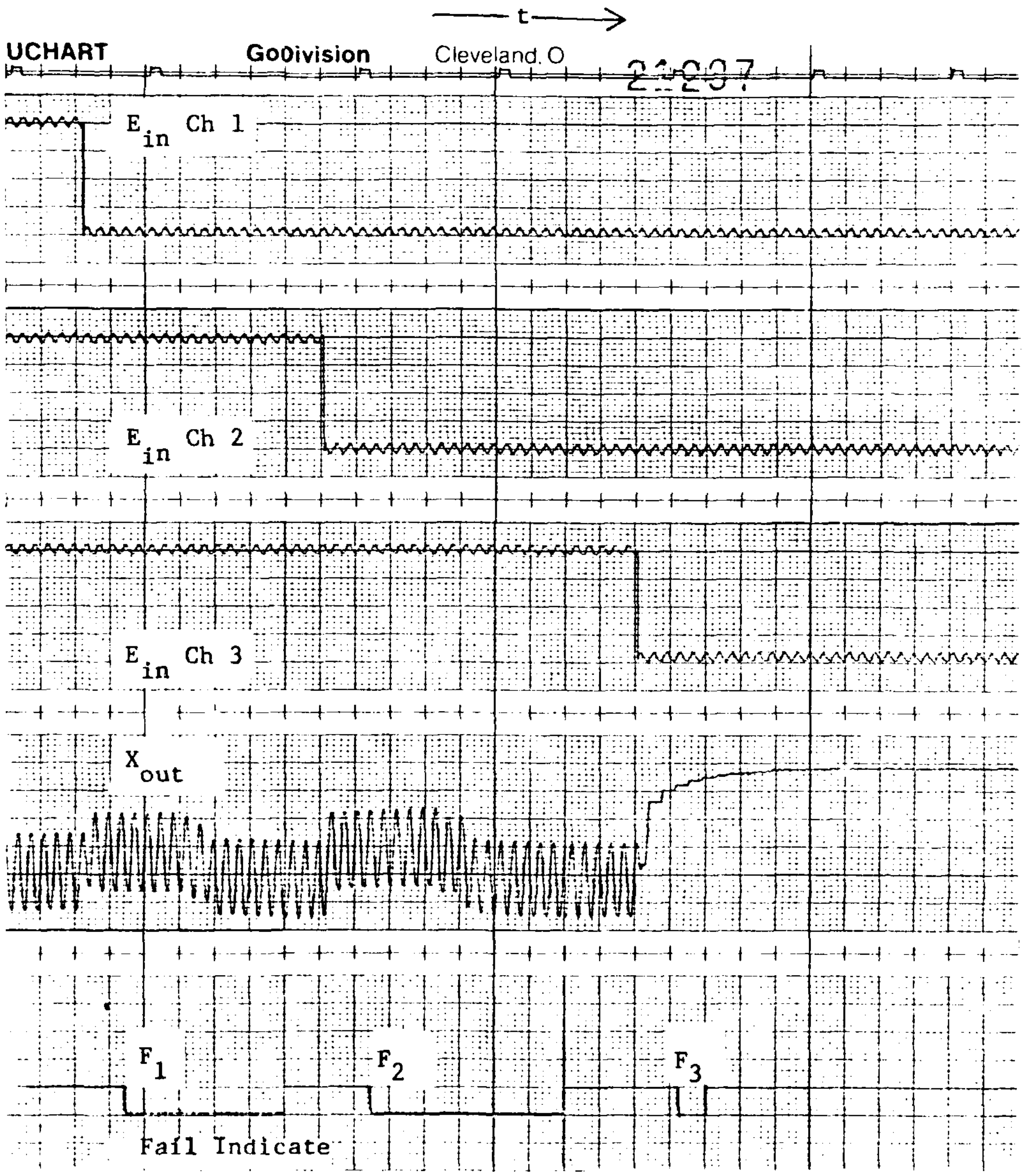
FIGURE 132 Failure Transients - Condition 22

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date
Prepared 6/12/79

TEST - Failure Transients - Condition 23




Scale: $E_{in}$ = 0.500 v/div

$X_{out}$ = 0.0033 in/div

t = 20 div/sec

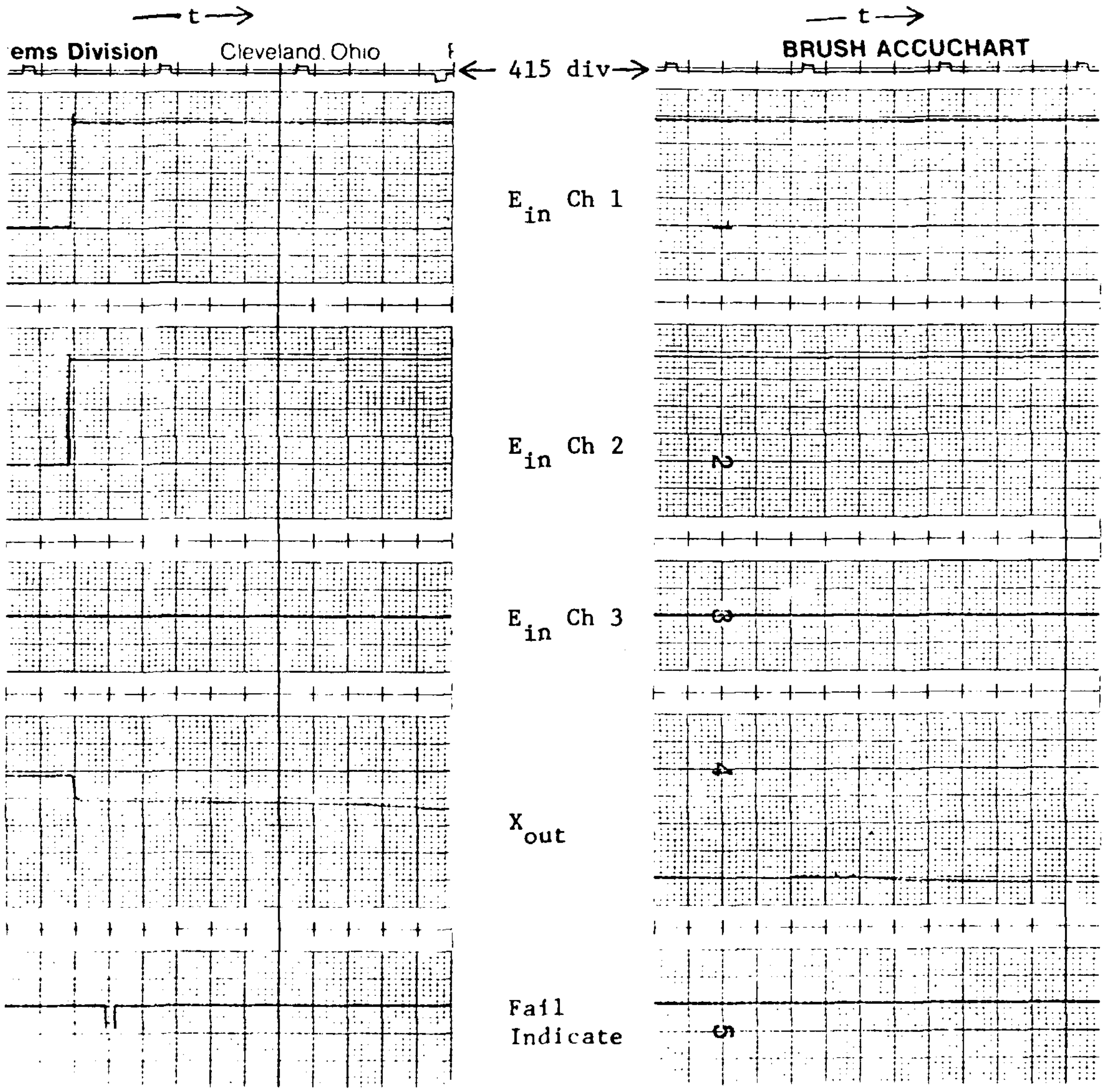
FIGURE 133 Failure Transients - Condition 23

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date Prepared 6/12/79

TEST - Failure Transients - Condition 24




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.0067 in/div
t = 20 div/sec

FIGURE 134 Failure Transients - Condition 24

fact that the output of the system does not go completely hardover indicates that the force capability of channel 4 has been increased to 100% so that channels 1 and 2 are offset in force output by channels 3 and 4.

Figures 135 shows the effect of applying a hardover input simultaneously to channels 1 and 2 with the actuator cycling at 10 Hz at a maximum unsaturated amplitude. Upon application of the hardover inputs, the actuator output stops showing a response to the 10 Hz input and moves to a position displaced from null 12.56% of the total actuator stroke. This result is similar to that obtained for Configuration A and B with the position displacement being larger (12.56% compared to 1.95% for Configuration A and 4.7% for Configuration B) and taking a longer time to reach. No failure is indicated by the failure logic. The position limit (as experienced with Configuration A) was unanticipated. The two channels opposing the hardover input channels do not have the same total force capability as the hardover channels, since channel 4 is limited to 50% force output until the failure logic detects a failure.

3.9.3.4 Slowover Input Transient

Figure 136 shows the effect of an extend slowover ramp of .4 volts/second applied to the input of channel 1. The maximum amplitude of the input is -.80 volts which is apparently not enough to cause the failure logic to vote a failure. A failure is voted at a +.45 volts for the retract polarity of the input. The output deviation for the test condition (retract or extend) is .50% of the maximum actuator stroke.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
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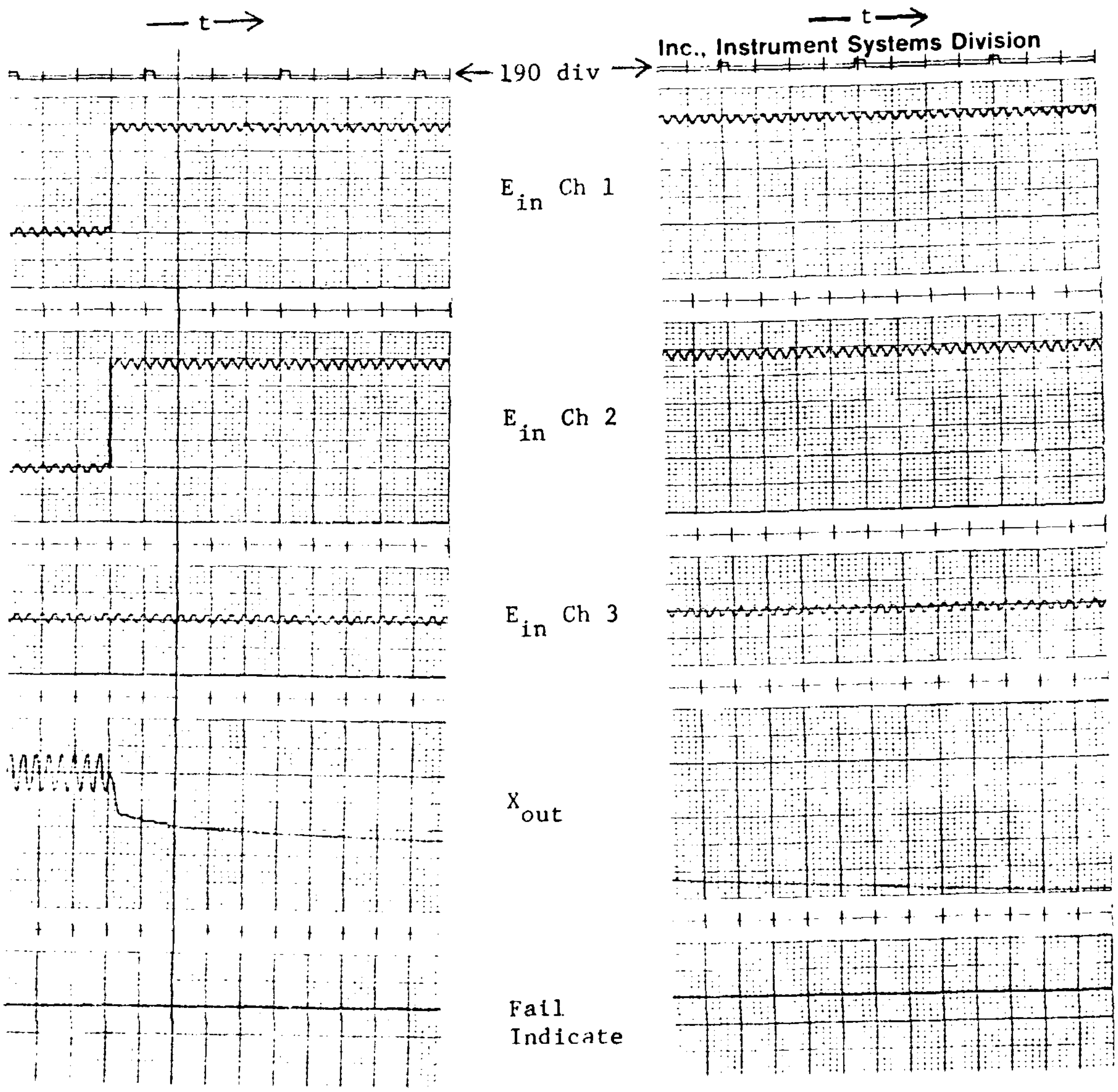
Prepared 6/12/79

TEST - Failure Transients - Condition 25




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.0067 in/div
t = 20 div/sec

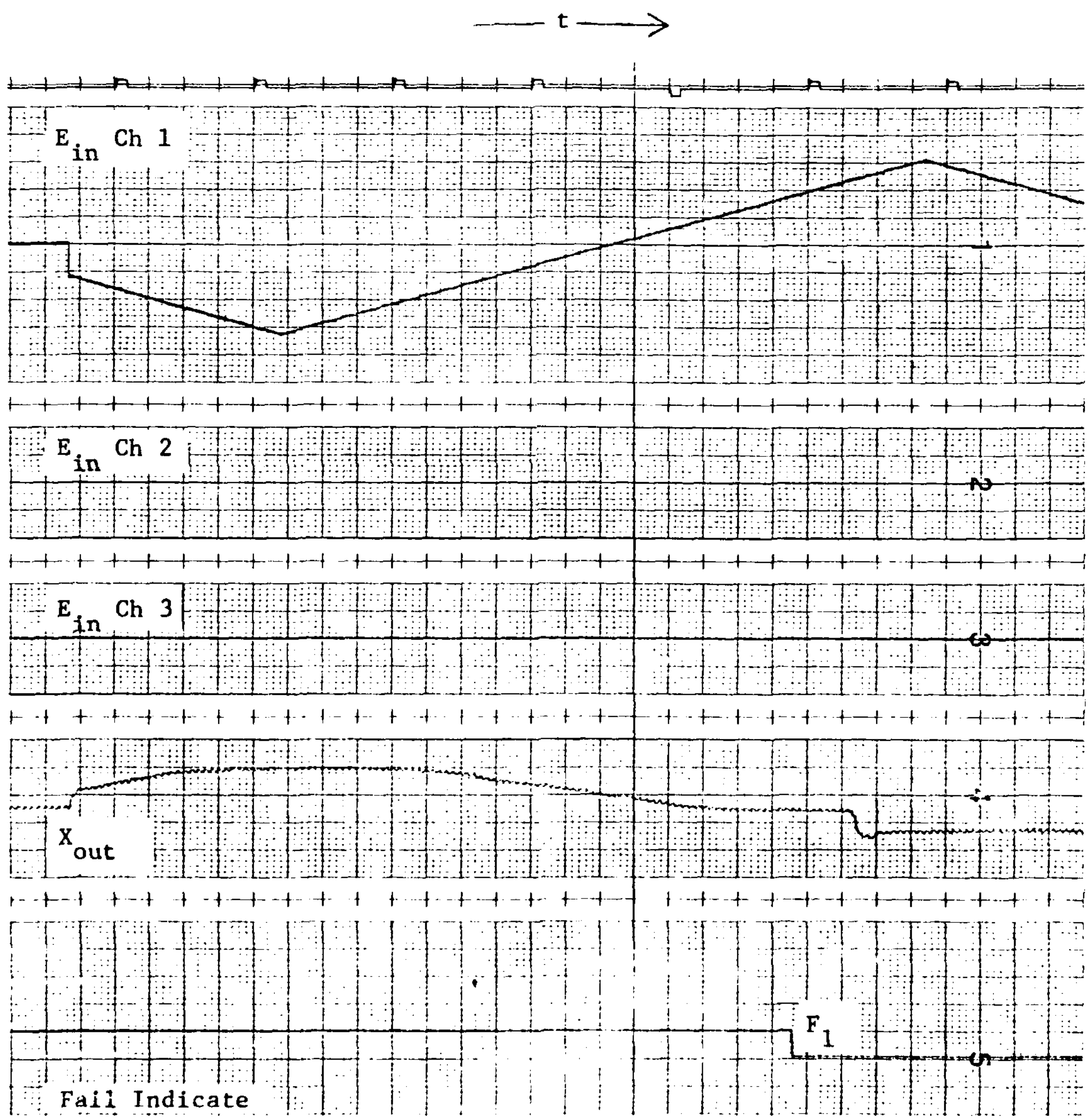
FIGURE 135 Failure Transients - Condition 25

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date
Prepared 6/11/79

TEST - Failure Transients - Condition 26 (1 Ch Extend)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.0013 in/div
t = 20 div/sec

FIGURE 136 Failure Transients - Condition 26 (1 Ch Extend)

Figure 137 shows the effect of a subsequent ramp input into channel 2 with channel 1 voted as failed. As with the failure ramp input applied first to channel 1, the extend polarity of the ramp does not cause the failure logic to vote a failure. The ramp input causes a failure to be detected at +.45 volts (a retract input polarity). The maximum deviation of the actuator output is .40% of the total actuator stroke.

Figure 138 shows the effect of the third extend ramp input failure applied to channel 3. The input amplitude is limited to -.80 volts. As with the same input applied to channels 1 and 2, the input does not cause a failure to be detected. The retract input of .60 volts does cause a failure to be voted. The output of the actuator deviates .55% of the maximum actuator stroke.

Figures 139, 140 and 141 show the effect of a retract input ramp applied sequentially to channels 1, 2 and 3. The results are similar to those shown on Figures 136, 137 and 138, since the retract input (rather than the extend) caused a failure to be voted on those figures.

The output deviations for the first retract input failure into channel 1 is .50% of the maximum actuator stroke. This deviation is similar to the .49% for Configuration A and the .42% for Configuration C.

The output deviation for the second failure into channel 2 is .35% of the maximum actuator stroke. This is less than the deviation of .49% for Configuration A and .89% for Configuration B.

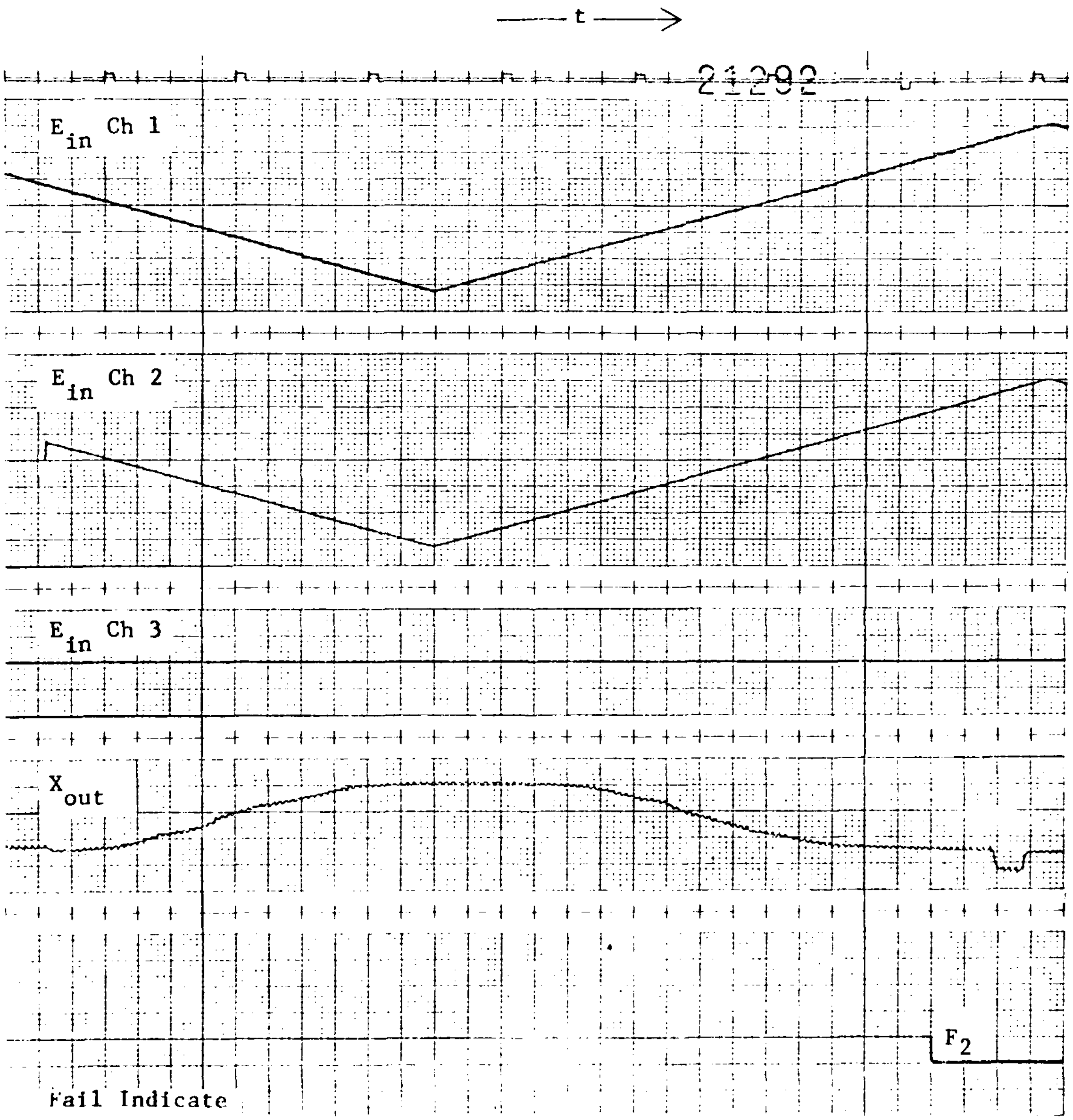
The output deviation for the third retract ramp input failure is .55% of the maximum actuator stroke and is less than that measured for Configurations A and B. The deviation for Configuration A was .88% and the deviation for Configuration B was .89%

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date
Prepared 6/11/79

TEST - Failure Transients - Condition 26 (2 Chs. Extend)




Scale: $E_{in}$ = 0.050 v/div

$X_{out}$ = 0.0013 in/div

t = 20 div/sec

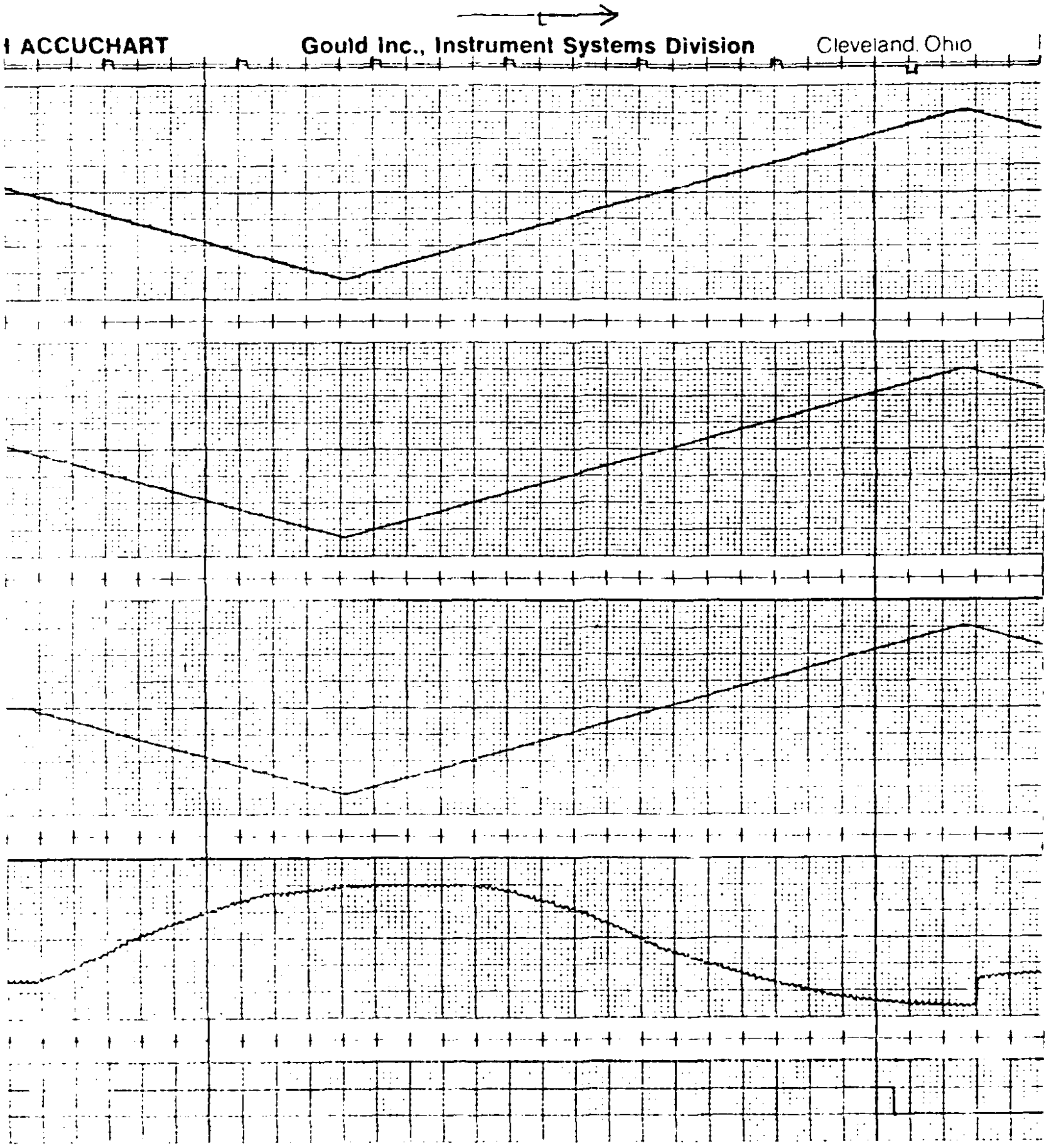
FIGURE 137 Failure Transients - Condition 26 (2 Chs. Extend)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date
Prepared 6/11/79

TEST - Failure Transients - Condition 26 (3 Chs. Extend)




Scale: $E_{in}$ = 0.050 v/div

$X_{out}$ = 0.0013 in/div

t = 20 div/sec

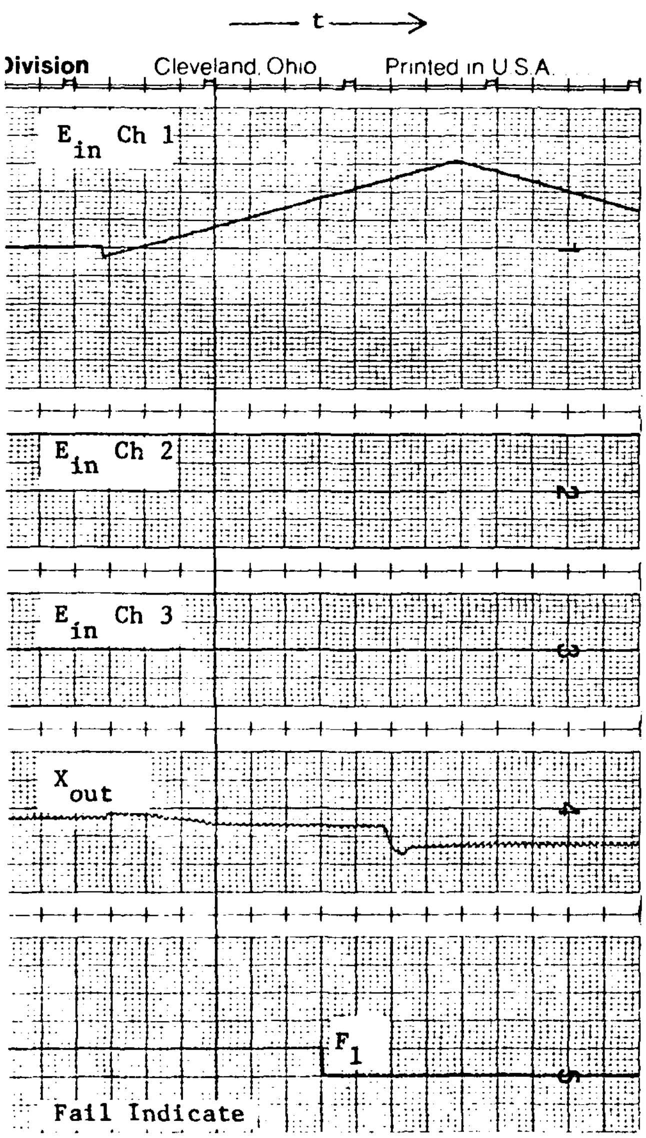
FIGURE 138 Failure Transients - Condition 26 (3 Chs. Extend)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date
Prepared 6/11/69

TEST - Failure Transients - Condition 26 ( 1 Ch Retract)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.0013 in/div
t = 20 div/sec

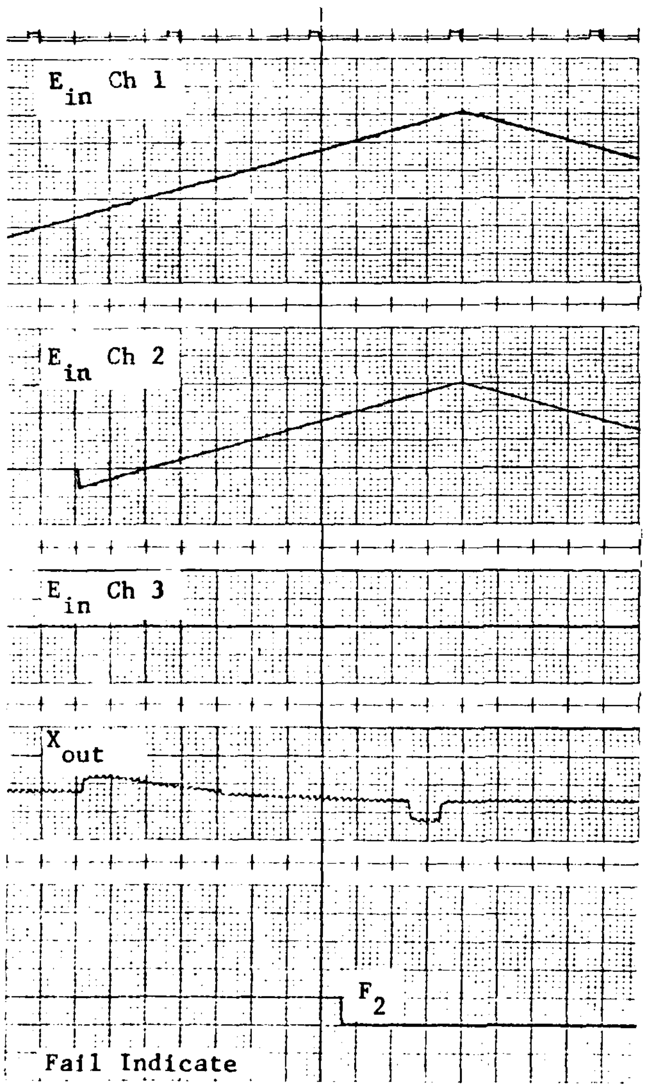
FIGURE 139 Failure Transients - Condition 26 (1 Ch Retract)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date
Prepared 6/11/79

TEST - Failure Transients - Condition 26 (2 Chs. Retract)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.0013 in/div
t = 20 div/sec

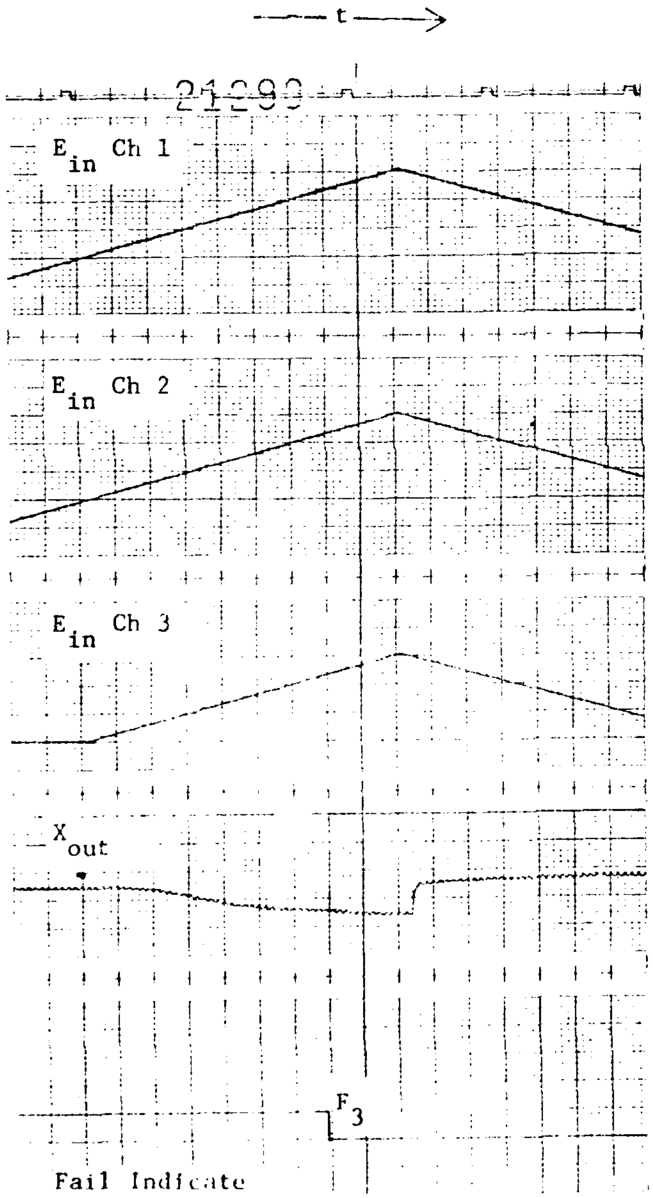
FIGURE 140 Failure Transients - Condition 26 (2 Chs. Retract)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date
Prepared 6/11/79

TEST - Failure Transients - Condition 26 (3 Chs. Retract)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.0013 in/div
t = 20 div/sec

FIGURE 141 Failure Transients - Condition 26 (3 Chs. Retract)

Figures 142 through 144 show the effect of applying a 0 to + 1 volt ramp at .4 volts/sec to channels 1, 2 and 3 sequentially with the system operating at 10 Hz and the maximum unsaturated amplitude. For the first two slowover input failures, as shown on Figures 142 and 143, the failure logic detects the ramp input as a failure. For the third ramp input applied to channel 3 (as shown on Figure 144), the failure logic does not latch, although the failure indicate for channel 3 does trip.

Figures 145 through 147 show the effect of applying a 0 to - 1 volt ramp at .4 volts/sec to channels 1, 2 and 3 sequentially with the system operating at 10 Hz at maximum unsaturated amplitude. The results are similar to those measured for the 0 to + 1 volt ramp. The failure logic identifies a channel 4 failure for the third failure input but does not latch. The first two failure inputs into channels 1 and 2 are detected correctly and the corresponding channel depressurized. The slowover input causes a null shift of the system output until the failed channel is depressurized. For the third failure input, the output of the actuator deviates until the deviation causes the remaining channel (without the ramp input) to force offset the failed channel. The force offsetting prevents the system output from responding to the 10 Hz input.

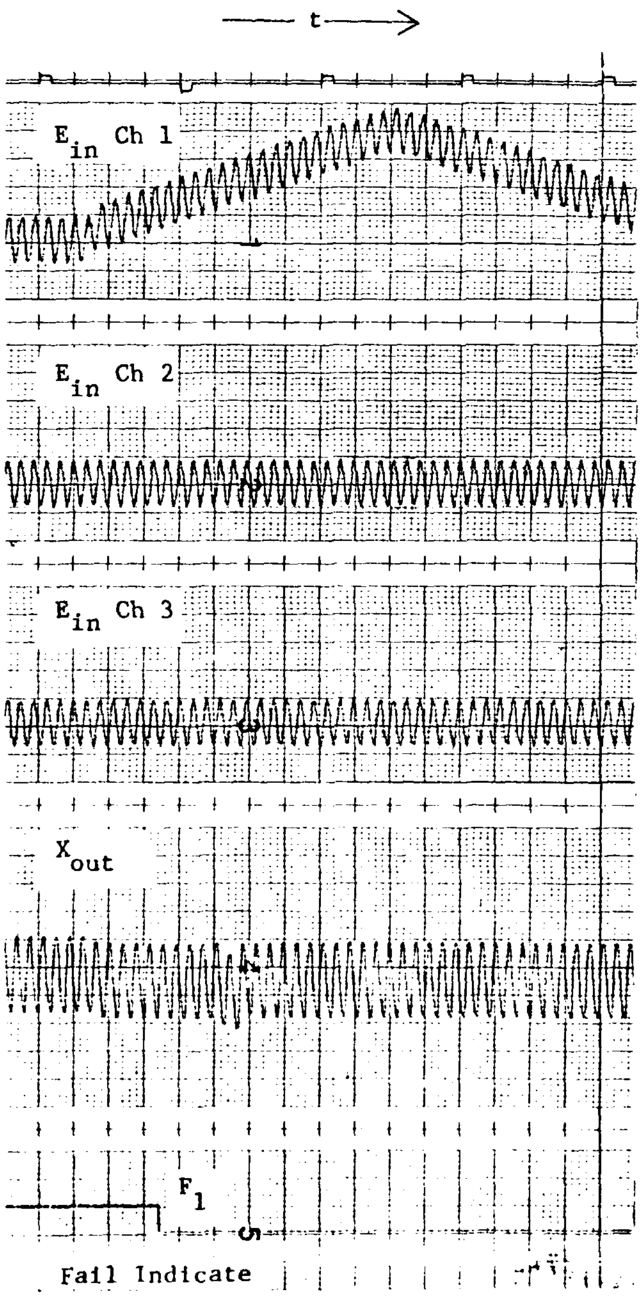
These results are similar to those measured on Configurations A and B and indicate that the equalizer integrators do not affect the failure detection for the test condition used.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date
Prepared 6/12/79

TEST - Failure Transients - Condition 27 (1 Ch Retract)




Scale: $E_{in}$ = .100 v/div
$X_{out}$ = 0.0033 in/div
t = 20 div/sec

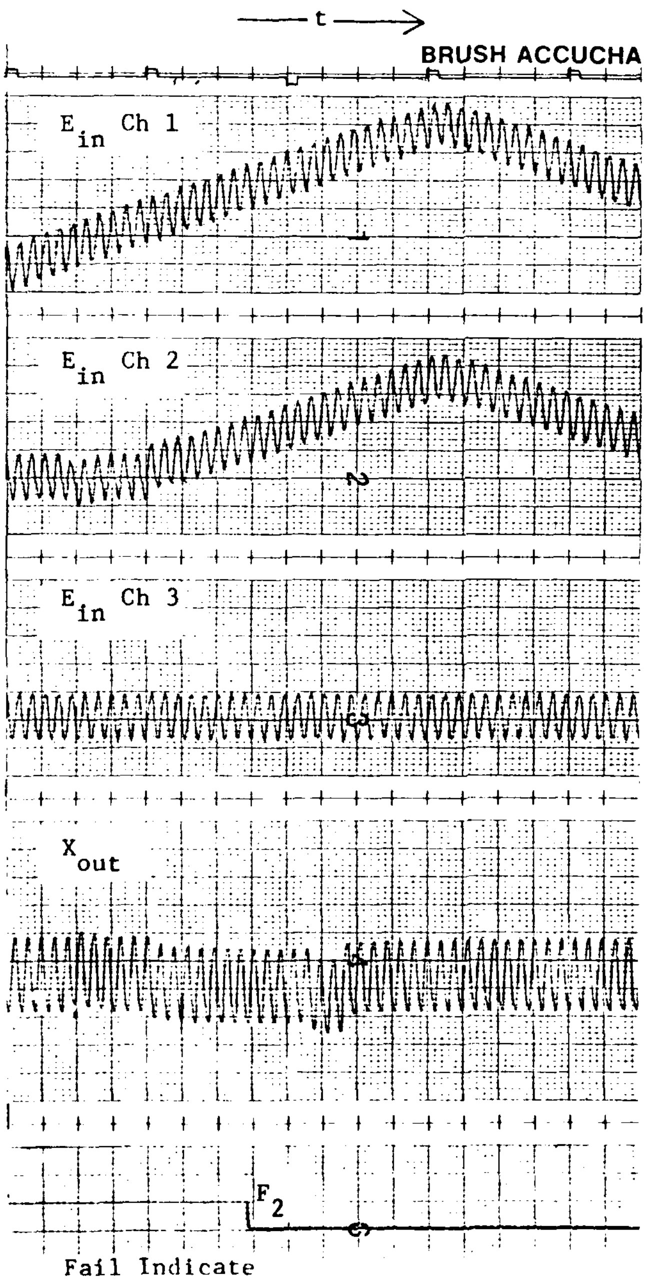
FIGURE 142 Failure Transients - Condition 27 (1 Ch Retract)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date
Prepared 6/12/79

TEST - Failure Transients - Condition 27 (2 Chs. Retract)




Scale: $E_{in}$ = .100 v/div
$X_{out}$ = 0.033 in/div
t = 20 div/sec

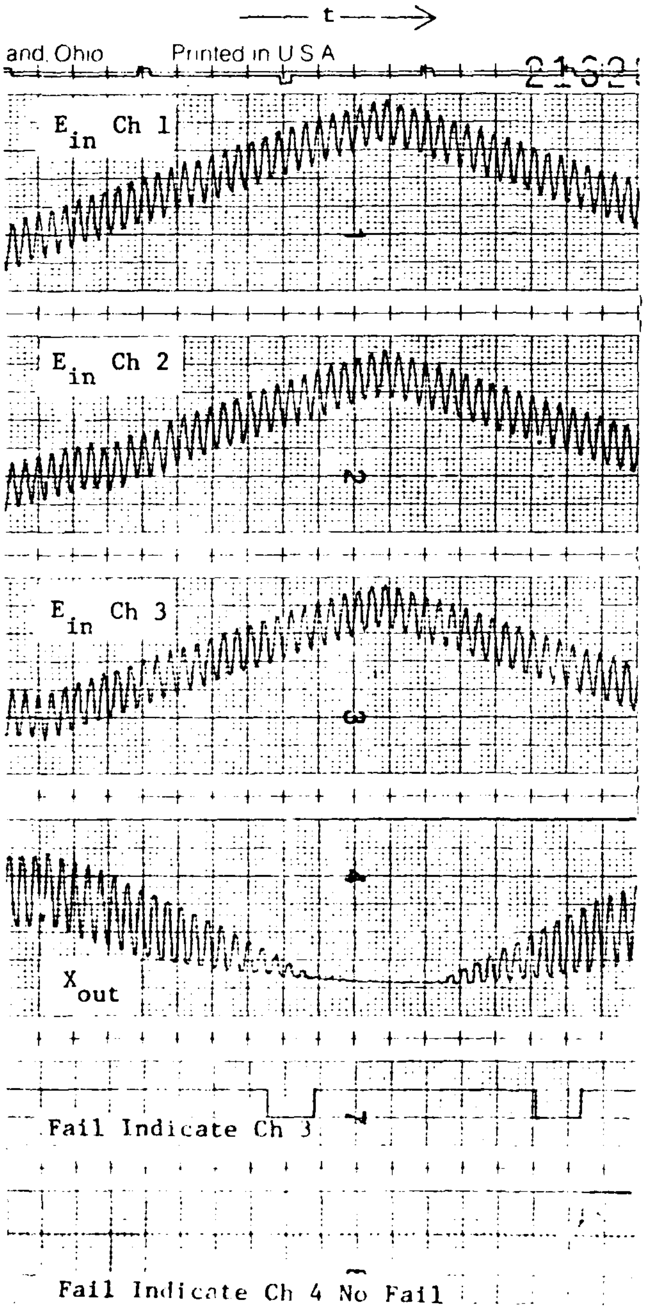
FIGURE 143 Failure Transients - Condition 27 (2 Chs. Retract)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date
Prepared 6/10/79

TEST - Failure Transients - Condition 27 (3 Chs. Retract)




Scale: $E_{in}$ = .100 v/div
$X_{out}$ = 0.033 in/div
t = 20 div/sec

FIGURE 144 Failure Transients - Condition 27 (3 Chs. Retract)

AD-A091 559 DYNAMIC CONTROLS INC DAYTON OHIO F/G 1/3
RESEARCH AND DEVELOPMENT OF CONTROL ACTUATION SYSTEMS FOR AIRCR--ETC
JUL 80 G D JENNEY F33615-77-C-3077
UNCLASSIFIED AFFDL-TR-79-3117-VOL-2 NL

4 of 5

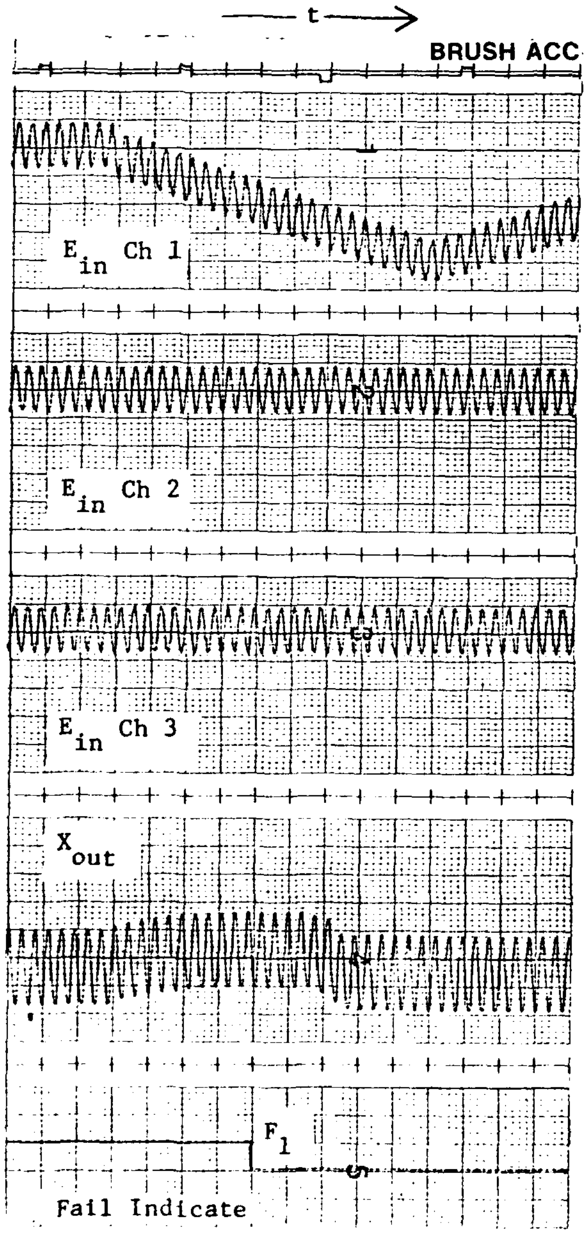
AD
A091559

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date
Prepared 6/12/79

TEST - Failure Transients - Condition 27 (1 Ch Extend)




Scale: $E_{in}$ = .100 v/div
$X_{out}$ = 0.033 in/div
t = 20 div/sec

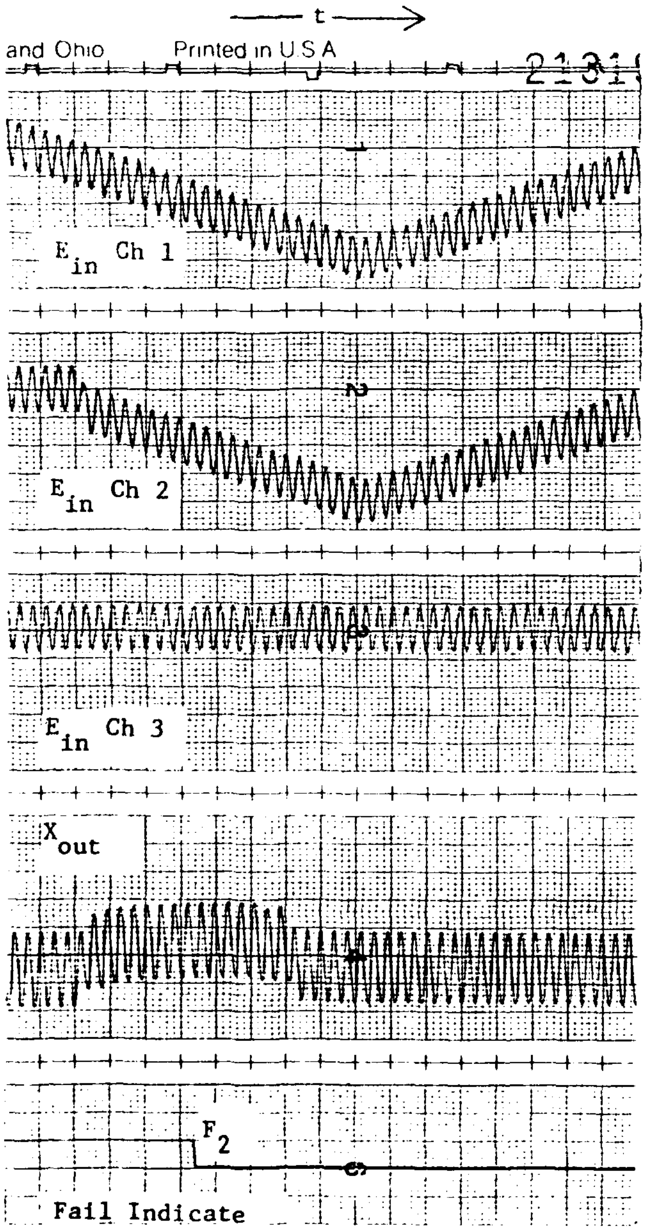
FIGURE 145 Failure Transients - Condition 27 (1 Ch Extend)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date
Prepared 6/12/79

TEST - Failure Transients - Condition 27 (2 Chs. Extend)




Scale: $E_{in}$ = .100 v/div
$X_{out}$ = 0.033 in/div
t = 20 div/sec

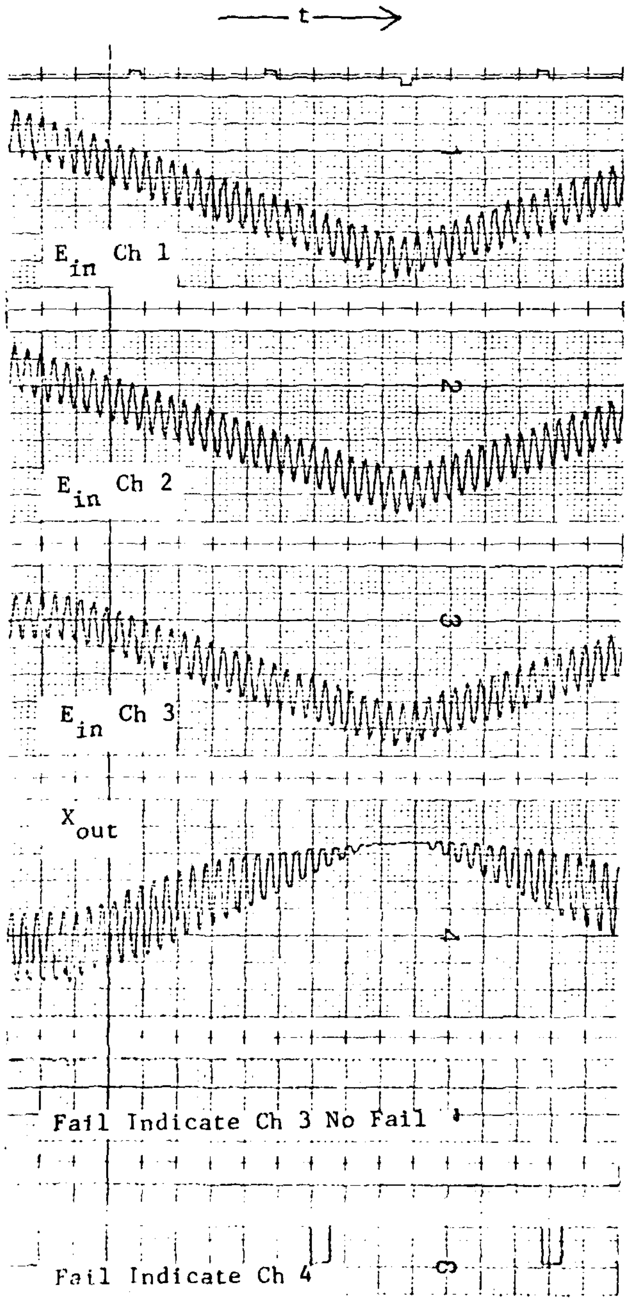
FIGURE 146 Failure Transients - Condition 27 (2 Chs. Extend)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date
Prepared 6/12/79

TEST - Failure Transients - Condition 27 (3 Chs. Extend)




Scale: $E_{in}$ = .100 v/div
$X_{out}$ = 0.033 in/div
t = 20 div/sec

FIGURE 147 Failure Transients - Condition 27 (3 Chs. Extend)

TABLE 26

Failure Detection Level - Static

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 6/29/79

TEST ITEM - Grumman - Bertea Unit
Configuration C

TEST - Failure Detection Level - Static

| Test Condition | Channel | Fail Voltage | |
|---|---|---|---|
| | | Extend | Retract |
| 1 | 1 | -0.900 | +0.500 |
| 1 | 2 | -0.600 | +1.150 |
| 1 | 3 | -0.500 | +0.500 |
| 1 | 4 | -0.450 | +0.400 |

### 3.9.4 Failure Logic Detection Characteristics

#### 3.9.4.1 General

This section described the results of testing conducted to establish the failure detection characteristics of Configuration C. The failure amplitude and time delay duration are the same as used for Configuration A and B. The test results present both the static detection level for each channel and the highest frequency at which an input amplitude of 110% of the static detection level is detected by the failure logic and causes the particular channel to be depressurized.

#### 3.9.4.2 Specific

Figures 148 through 151 show the data taken to establish the failure detection level for channels 1, 2, 3 and 4 while the other channel inputs are grounded. The amplitude of the input at channel failure indication is taken as the failure detection level.

Table 26 lists the extend and retract direction failure detection input voltages for each channel of Configuration C. As with Configuration A and B, the channel 4 failure detection level is lower than that of the other 3 channels. The failure detection level itself is similar to that of Configuration B in terms of the sum of the retract and extend input voltage for each channel. The individual retract and extend voltages vary somewhat from those measured on Configuration B. The total failure voltage (sum of the retract and extend voltages) are the same as Configuration B (1.4 vs. 1.45) for channel 1 and greater than Configuration B for channel 2 (1.75 vs 1.30 volts). Channel 3's failure voltage total is 1.00 volt compared to Configuration B's 1.20 volts. Channel 4's failure voltage for both Configuration B and C is essentially the same (.85 vs .80 volts). These results indicate that the equalizer integration does affect the failure detection levels slightly. However, the effect is that of shifting the offset positions of the individual channels rather than an increase in the failure detection total voltages. As with Configuration B, the failure detection level of Configuration B is approximately twice that of Configuration A, due to the operation of the equalizer circuits.

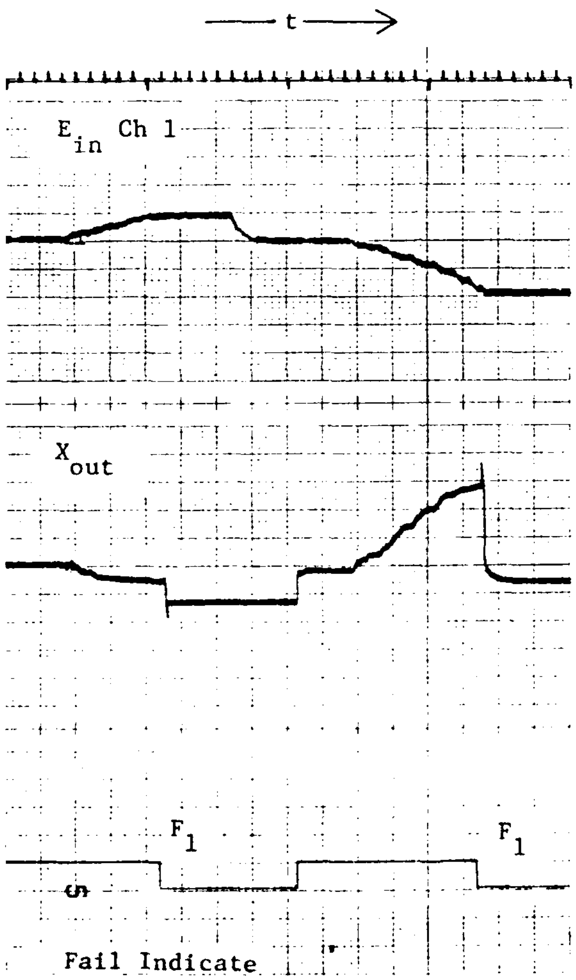
Figure 152 shows the data taken to establish the dynamic failure detection capability of channel 2 for Configuration C. As shown on Figure 152, the frequency of the input signal is reduced with increasing time until the fail indicate output latches. This frequency is the lowest frequency that a peak to peak input of 110% of the static failure level input will cause the failure logic to trip and latch. Table 27 lists the highest frequency at which the failure logic votes a failure for a particular channel. The dynamic failure level frequencies are similar to those obtained for Configuration B, indicating that the integration of the equalizer outputs has little effect upon the dynamic failure detection capability of Configuration C.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date Prepared 6/14/79

TEST - Failure Detection Level - Static - Ch 1




Scale: $E_{in}$ = 0.100 v/div
$X_{out}$ = 0.0007 in/div
t = 2 div/sec

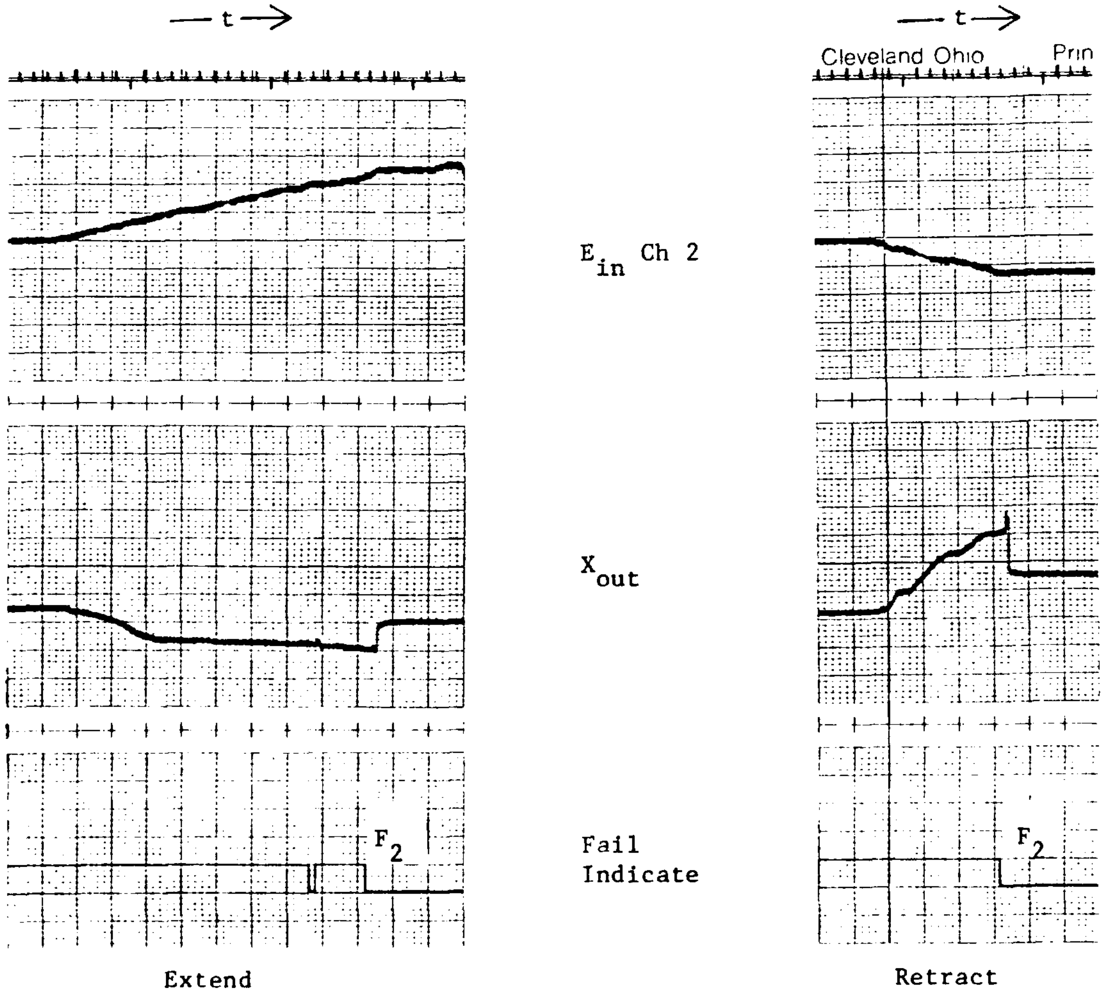
FIGURE 148 Failure Detection Level - Static - Ch 1

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date
Prepared 6/14/79

TEST - Failure Detection Level - Static - Ch 2




Scale: $E_{in}$ = 0.100 v/div
$X_{out}$ = 0.0007 in/div
t = 2 div/sec

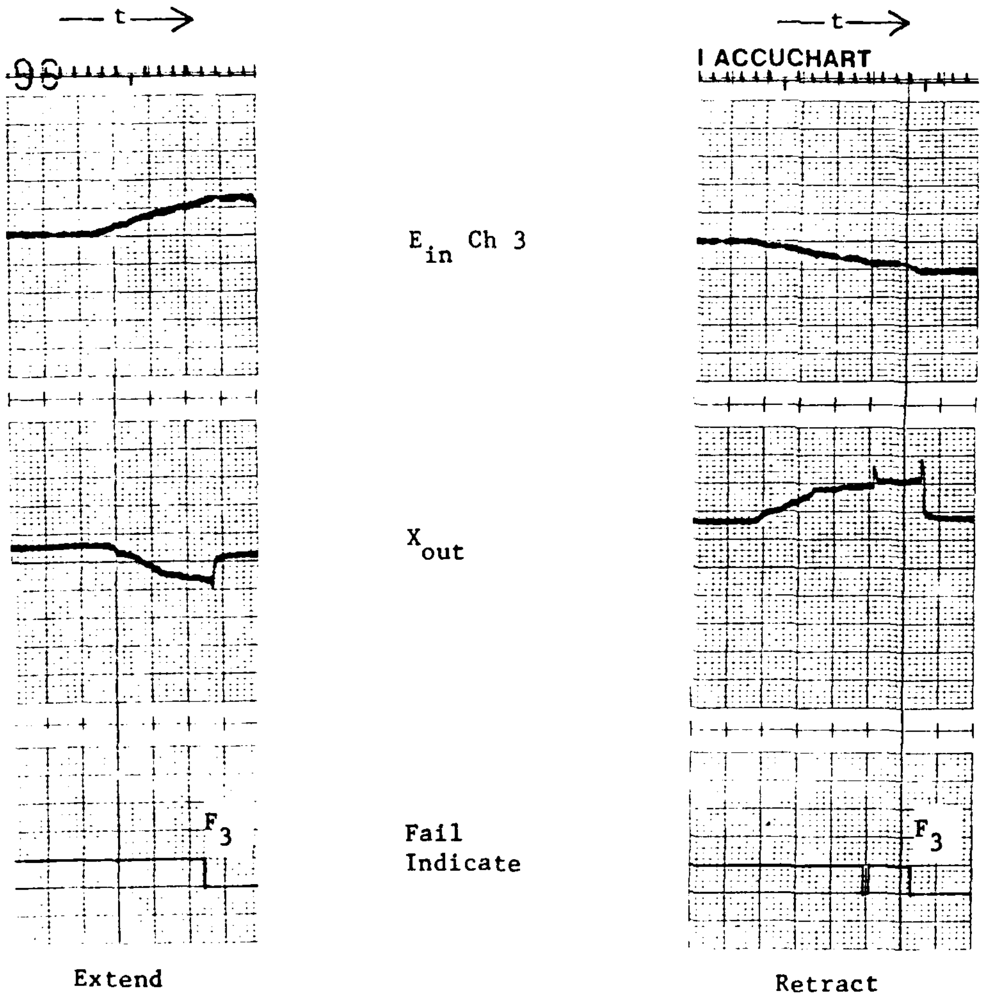
FIGURE 149 Failure Detection Level - Static - Ch 2

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date Prepared 6/14/79

TEST - Failure Detection Level - Static - Ch 3




Scale: $E_{in}$ = 0.100 v/div
$X_{out}$ = 0.0007 in/sec
t = 2 div/sec

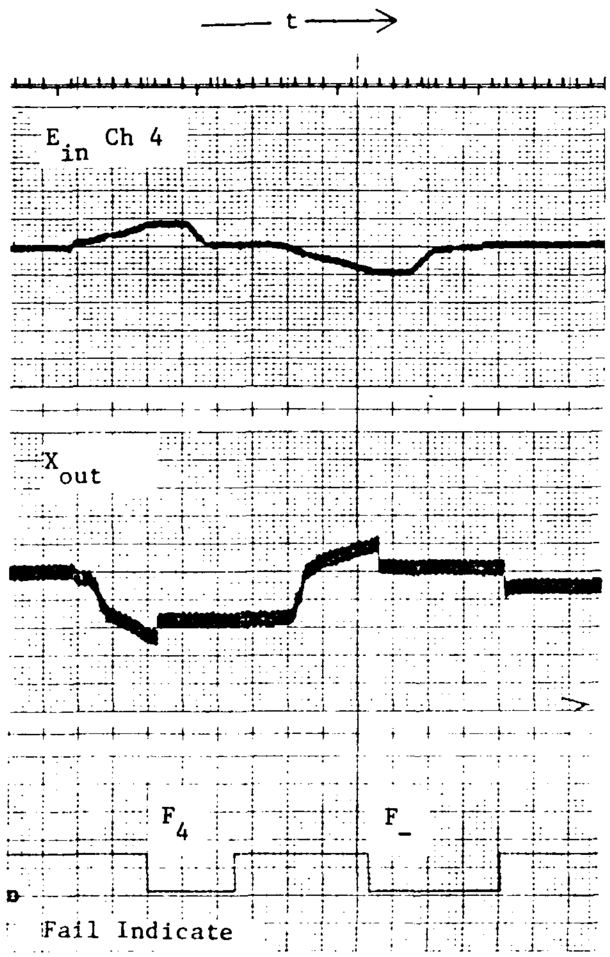
FIGURE 150 Failure Detection Level - Static - Ch 3

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date
Prepared 6/14/79

TEST - Failure Detection Level - Static - Ch 4




Scale: $E_{in}$ = 0.100 v/div
$X_{out}$ = 0.0013 in/div
t = 2 div/sec

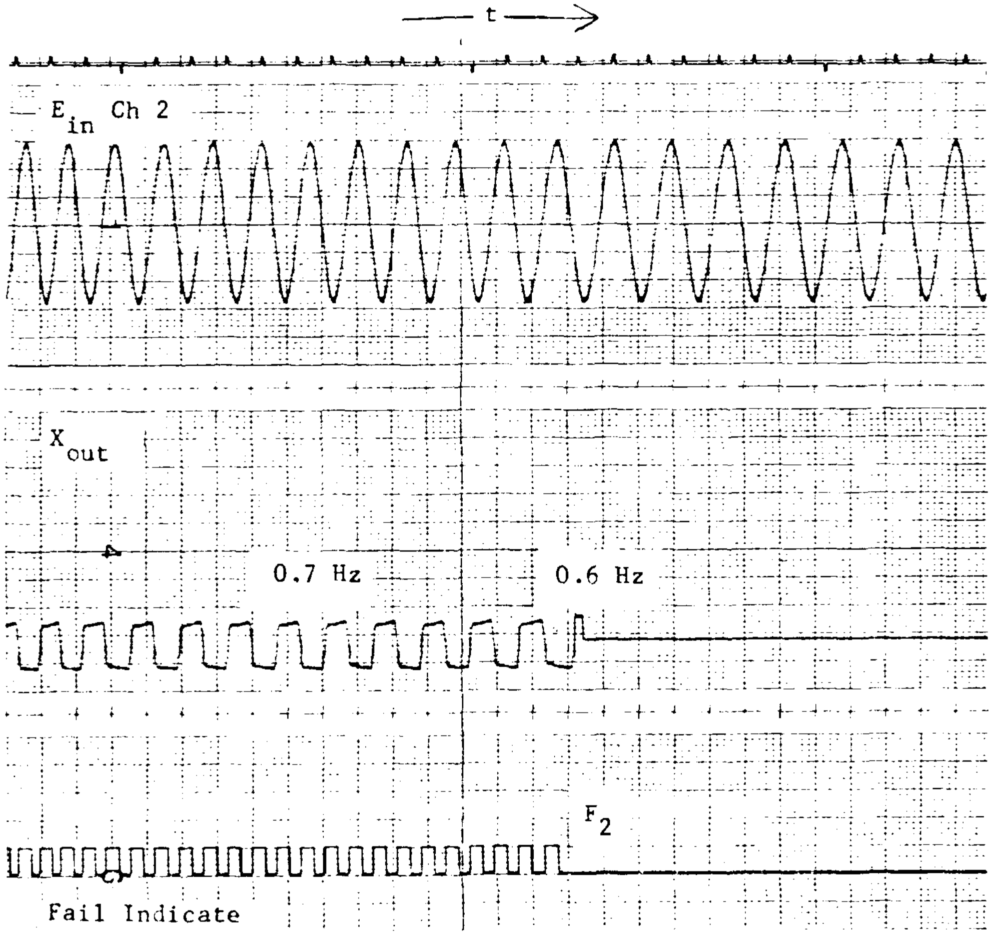
FIGURE 151 Failure Detection Level - Static - Ch 4

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - Bertea Unit
Configuration C

Date
Prepared 6/28/79

TEST - Failure Detection Level - Dynamic - Ch 2




Scale: $E_{in}$ = 0.100 v/div
$X_{out}$ = 0.0013 in/div
t = 5 div/sec

FIGURE 152 Failure Detection Level - Dynamic - Ch 2

TABLE 27

Failure Detection Level - Dynamic

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 6/29/79

TEST ITEM - Grumman - Bertea Unit
Configuration C.

TEST - Failure Detection Level - Dynamic

| Test Condition | Channel | Fail Hz |
|---|---|---|
| 1 | 1 | 0.8 |
| 1 | 2 | 0.6 |
| 1 | 3 | 0.6 |
| 1 | 4 | 0.9 |

## 4.0 EVALUATION SUMMARY FOR THE FORCE SHARING MECHANIZATIONS

As tested, the mechanization performs the intended function of providing a "two failure" tolerant redundancy mechanization. This is true of all three configurations evaluated. Third failure effects were measured and indicated in the test data. However, the failure logic was not designed to correctly detect the third failures and did not in many cases.

The effect of the pressure equalizer operation on the basic force sharing system was to increase the input mismatch tolerance of the system without changing the output amplitude transient upon failure detection. The effect of using integrators with the pressure equalizers did improve the static threshold of the mechanization compared to the configuration with "non-integrated" equalizer outputs. However, the threshold of the basic force sharing system was better for most test conditions than either of the equalized systems.

The frequency response characteristics of the mechanization for all test conditions remained quite constant, a desirable characteristic. Typical output amplitude deviations for slow or hardover failures remained below 1% of the total actuator stroke.

The negative aspects of the configuration evaluated are the high threshold levels compared to a normal electrohydraulic control actuator and the limited dynamic range of the failure detection mechanization. The threshold is probably an inherent penalty of using low pressure gain control valves required by the force sharing mechanization. The failure logic dynamic response characteristics could probably be improved by a careful redesign.

## 5. ACTIVE/ON-LINE FBW SYSTEM EVALUATION

### 5.1 Introduction

The active/on-line configuration evaluation was a three-channel secondary electrohydraulic configuration developed by the National Water Lift Company of Kalamazoo, Michigan. The configuration was designed as a development tool and provided flexibility of the failure detection levels and control element gains used with the control actuator.

Figures 153 and 154 show the two principle components of the demonstrator. Figure 153 shows the control actuator section of the demonstrator. This section consisted of three actuators connected in parallel to a common output link. Figure 154 shows the front panel of the electronics console used with the actuator section of the demonstrator. The console front panel included test points and relay control switches to allow convenient changing of the test conditions for the demonstrator. Although the demonstrator could also have been operated in an active/standby configuration or a force sharing system configuration, only the active/on-line configuration was evaluated.

In evaluating the mechanization for specific failures, no attempt was made to create internal failures in either the control electronics or the actuator. The failures simulated were created by failing the inputs to the demonstrator. These inputs were both the electrical control and hydraulic power inputs. These failures do not address directly internal failure modes possible within the particular mechanization. It was assumed that common mode failures were not part of the mechanization design and that the effect of internal failures of a control channel fall within the extremes of the hardover and slowover input failures used for the evaluation testing.

FIGURE 153 Control Actuator Section - Active/On-Line System

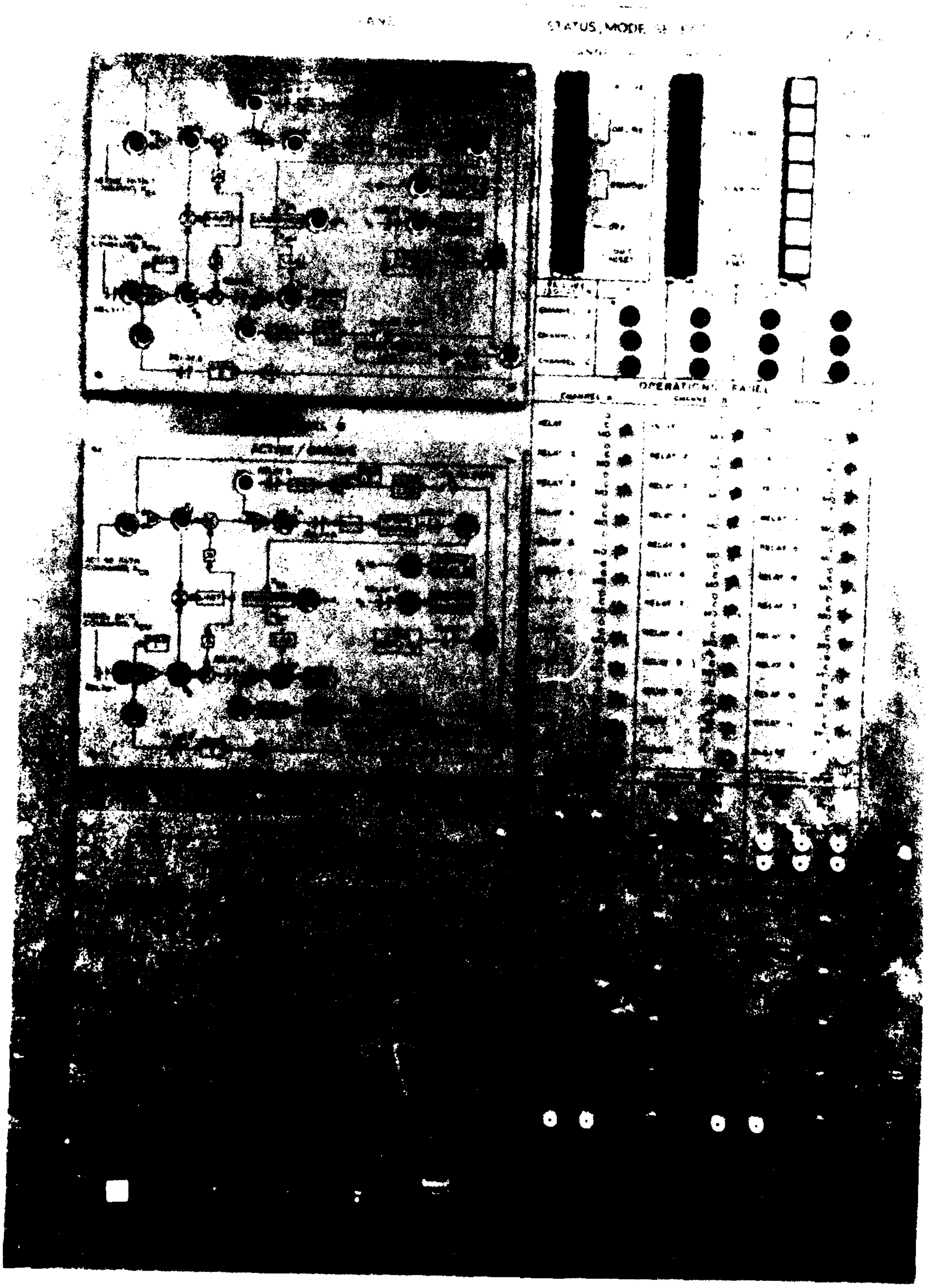


FIGURE 154 Control Electronics Section - Active/On-Line System

The active/on-line demonstrator was designed to represent the secondary actuator approach to a FBW mechanization. The output of the demonstrator would normally be connected as an input to the power actuator driving a control surface.

## 5.2 Hardware Description

The actuator package for the active/on-line configuration is an electrohydraulic three channel configuration. Only one channel at a time is allowed to provide the output force for the actuator section. This is accomplished by using selectively switched negative pressure feedback around the "on-line" channels of the configuration to prevent the channels from causing a force fight with the active channel. This potentially eliminates the threshold problems encountered with force sharing systems and allows using high pressure gain two stage electrohydraulic control valves which can provide low threshold for the system.

In the event of a control channel failure, the failure logic assigns the "active" channel roll to a correctly operating channel and bypasses the failed channel. Figure 155 is a block diagram schematic of one of the control channels of the demonstrator unit. Note that each channel requires two input control voltages, one for a command channel and one for a model of the command channel. The control channel also uses two position feedback transducers for the output actuator motion, one for the command and one for the model section of the control channel. Input and position feedback failures are detected by comparator $K_4$ shown on Figure 155. The command and model input signals are averaged downstream of the comparator $K_4$ and connected to the servoamplifiers for the command and model sections. As shown on Figure 155, a second failure detection section is used to detect servovalve and servoamplifier failures. This section, consisting of comparator $K_1$ and a latch, compares the output of a position transducer connected to the command section servovalve spool and the output of a second order filter used as a model for the servovalve.

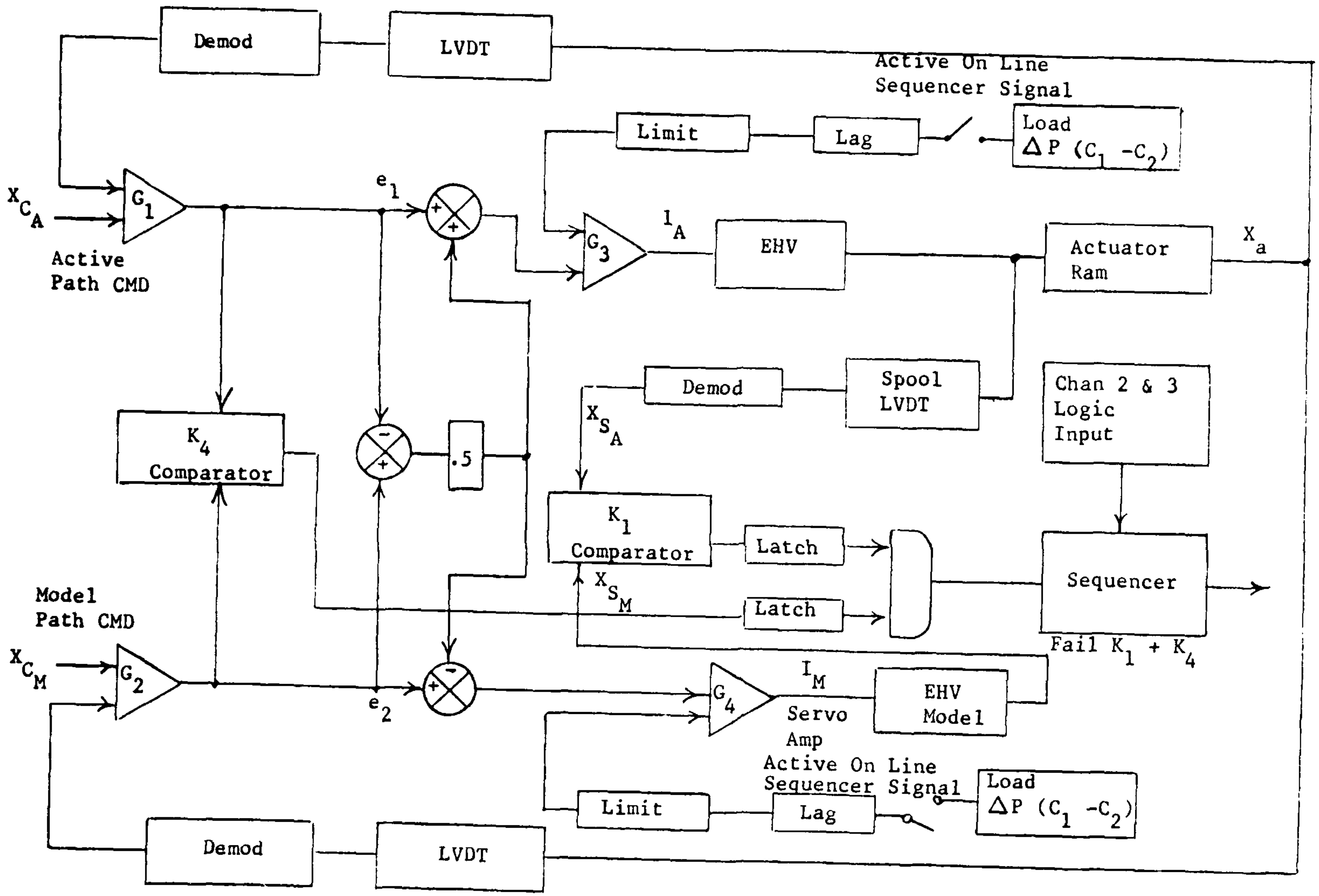



FIGURE 155 Three-Channel Active/On-Line Actuator Schematic (Single Channel Shown)

Note on Figure 155 the load differential pressure control block, the output of which is switched by the sequencer. This is the negative pressure feedback that is used to effectively eliminate the output force capability of a control channel and place it in the "on-line" operational mode. The output signal of the load differential pressure block is passed through a low pass or "lag" filter and an amplitude limiter. The low pass filter prevents the pressure feedback loop from being effective in eliminating the force output of the control channel at high frequencies. The limiter prevents the feedback path from operating at high differential pressures. This retains some of the advantages of a force fighting system in terms of the ability of the correctly operating control channels to force offset and prevent the hardover output of an active channel with a hardover input failure.

As shown on Figure 155, a failure sequencer is required to determine the operational mode of each control channel. The information used as an input to the sequencer is the failure logic outputs for the particular channel sequencer and the logic output of the other two channels. Note that the failure logic requires no cross channel monitoring and comparison in order to determine control channel component or input failures, but does require that the sequencer interconnect the control channels for correct operating status.

To disconnect a failed channel, a solenoid operated bypass and shutoff valve is used with the servovalve of each control channel. Upon solenoid de-energization or loss of system pressure, the solenoid valve interconnects the control ports of the servovalve to return and blocks the system pressure to the electrohydraulic servovalve.

To allow the control actuators to withstand backdriving by the other control channels without damage, the actuators incorporate spring-loaded relief valves that interconnect the cyclinder ports if the actuator differential pressure exceeds 3600 psi.

The servovalves used with the demonstration unit are two-stage flapper/nozzle electrohydraulic units manufactured by Hydraulic Research, a division of Textron, Inc. The valves are $\pm 8$ ma, 1000 ohm coil, valves with a flow rating of .45 GPM and a pressure gain of 4000 to 8000 psi/ma. The servovalves incorporate position LVDTs to measure the position of the second stage valve spool.

Each channel is equipped with a differential pressure transducer to sense the difference between supply and return pressures. The signal from this transducer is used to initiate failure shutdowns upon the loss of hydraulic supply pressure. The hydraulic failure detection capability is required for the configuration since hydraulic failures of an active channel will create an open loop condition for the system, since the on-line channels do not contribute to the force output of the system.

The demonstrator actuator of the system weighed approximately 45 lbs and measured 13 x 10 x 9 inches. The actuator was equipped with ¼ inch pressure and return lines and used standard MS fittings. The system was designed for a supply pressure of 3000 psi and MIL-H-5606 hydraulic fluid. The specific sizing parameters for the actuator portion of each channel were:

| | |
|---|---|
| Actuator Drive Area | .34 $in^2$ |
| Actuator Stroke | $\pm$ .75 in |
| Summing Link Output | +1.00 in |
| Maximum Actuator Flow | .44 GPM |

5.3 Operational Description

The active/on-line configuration uses three actuator channels, one in an "active" mode and the other two in an "on-line" mode. The particular mode selection for a particular channel is arbitrary.

The on-line channels are pressurized but do not contribute to the force output of the system during low frequency input or steady state operation.

The on-line operation of two control channels is accomplished with the pressure feedback inner loops used for those channels. On-line channel dynamic load sharing (and high load conditions) is provided by the use of a low pass or lag filter in the pressure feedback loop and the use of amplitude limits for the feedback signal. Since the negative pressure feedback signal is attenuated with increasing frequency of the signal, the on-line channels assist in driving the system output at input frequencies above the pressure feedback rolloff frequency. The amplitude limits of the pressure feedback signal prevent the pressure feedback from operating above differential pressure of approximately 750 psi. This allows the on-line channels to force offset large channel mismatches while accepting small mismatches without performance degradation.

In the active channel the pressure feedback loop is open, allowing that channel to full-force output in controlling the actuator's position. Since a high pressure gain valve is used, the operational characteristics of the channel (and system) are similar to a non-redundant electro-hydraulic secondary actuator in terms of threshold and frequency response.

The logic electronics utilize a sequencing network which (as provided for the demonstrator) is non-redundant and susceptible to single point failures. For a flight qualified system, the sequencer would require incorporation of redundancy to prevent single point failure from disabling the circuit and the failure mode sequencing of the control channels. The failure logic also incorporates failure signal latching to retain the failure declaration until the logic is manually reset.

Figure 156 is a block diagram of a control channel with the values for the gain and control elements used for the demonstrator testing. The parameters used for the general system evaluation are:

| | |
|---|---|
| Operating Pressure | 3000 PSI |
| Maximum Actuator Stroke | ±.600 inches |
| Nominal Position Loop Gain | 125 radians/sec |
| Failure Detection Level (Input Failures) | 10% of the maximum input voltage |
| Maximum Input Control Voltage | ± 10 volts |
| Servovalve Failure Detection Level | ± 40% of the maximum spool stroke |

The selection of the particular loop gain used was made in order to keep the nominal response of the system the same as that for previously evaluated systems (and the same as that used for the force sharing mechanization also evaluated in this report).

In addition to the parameter values indicated on Figure 156, the following performance settings were used:

| | |
|---|---|
| Servovalve and Model Comparator Time Delay | .050 sec. |
| Input Comparator Time Delay | .025 sec. |
| Input Comparator Reset Time | .010 sec. |
| Pressure Feedback Lag Time Constant | 5.0 sec. |

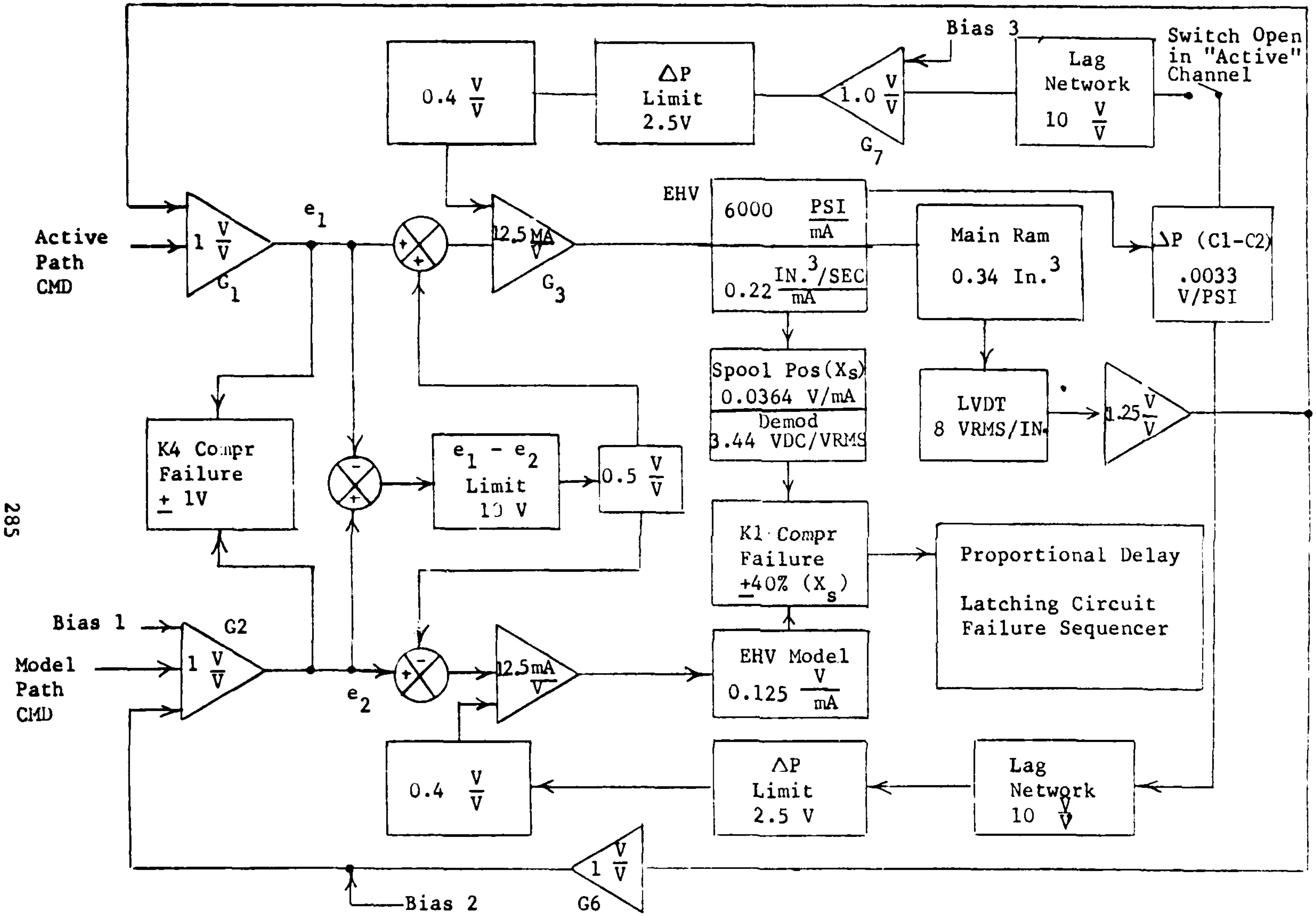



FIGURE 156 Active/On-Line Active Standby: Nominal Loop Values

The sequencer would require incorporation of redundancy to prevent single point failure from disabling the circuit and the failure mode sequencing of the control channels. The failure logic also incorporates failure signal latching to retain the failure declaration until the logic is manually reset.

Figure 156 is a block diagram of a control channel with the values for the gain and control elements used for the demonstrator testing. The parameters used for the general system evaluation are:

| | |
|---|---|
| Operating Pressure | 3000 PSI |
| Maximum Actuator Stroke | ±.600 inches |
| Nominal Position Loop Gain | 125 radians/sec |
| Failure Detection Level (Input Failures) | 10% of the maximum input voltage |
| Maximum Input Control Voltage | ± 10 volts |
| Servovalve Failure Detection Level | ± 40% of the maximum spool stroke |

The selection of the particular loop gain used was made in order to keep the nominal response of the system the same as that for previously evaluated systems (and the same as that used for the force sharing mechanization also evaluated in this report). The stroke for maximum position of the actuator was decreased below the mechanical limits of the actuator. The stroke used as the maximum position was ± .600 inches, while the available mechanical stroke was ± 1.000 inches. The stroke reduction was made in conjunction with the loop gain selection to allow operating the test system at a 10% input command level without rate saturation. The 10% unsaturated command input is typical of many flight control systems and is (with the exception of the Bertea Force Sharing System) the same setup criteria previously used for FBW system evaluation. The Bertea Force Sharing System could not be adjusted to run at over 4% unsaturated command settings without having the failure detection logic operate out of its design range.

In addition to the parameter values indicated on Figure 156, the following performance settings were used:

| | |
|---|---|
| Servovalve and Model Comparator Time Delay | .050 sec. |
| Input Comparator Time Delay | .025 sec. |
| Input Comparator Reset Time | .010 sec. |
| Pressure Feedback Lag Time Constant | 5.0 sec. |

5.4 Specific Test Procedure - Active/On-Line System

Table 28 lists the 32 test conditions and the values used for evaluating the active/on-line system. Test conditions of 1 through 11 are the various operational modes of the system. For each of these operational modes, the performance measurements described previously in Section 2.2.1 of this report were used to document the performance characteristics. The other test conditions correspond to the "Failure Effect on Performance" measurements described in Section 2.2.2 and the "Input Deviations Effect" measurements described in Section 2.2.3.

Test conditions 12 through 32 correspond to "Failure Removal Transients" measurements described in Section 2.2.4. The test conditions 12 through 27 state both the initial conditions and the test used for creating the transient condition.

Table 28 describes the various test conditions in terms of control channels A, B and C. This is different channel labeling than used previously with the Bertea system and was used simply to agree with visible labeling of the actuator channels as provided on the test system.

TABLE 28

TEST CONDITIONS

Grumman - National Water Lift Unit

| Test Condition | Test Condition Description |
|---|---|
| 1 | Baseline - all channels nulled, pressurized (3000 psi) and operating correctly. |
| 2 | One channel ($C_2$) electrical failure.* |
| 3 | Two channels ($B_1$ & $C_2$) electrical failure. |
| 4 | One channel ($B_a$) hydraulic failure. |
| 5 | Two channels ($A_a$ & $C_1$) hydraulic failure. |
| 6 | One channel ($A_a$) with negative offset to active input (biased to 90% of trip level). |
| 6a | One channel ($A_a$) with negative offset to model input (biased to 90% of trip level). |
| 7 | One channel ($A_a$) with positive offset to active input (biased to 90% of trip level). |
| 7a | One channel ($B_1$) with positive offset to active input (biased to 90% of trip level) and without $\Delta p$ compensation (via relay #11). |
| 8 | Two channels ($A_a$ & $B_1$) with negative offsets to active inputs (both channels biased negatively to 90% of trip level). |
| 8a | Two channels ($B_1$ & $C_2$) with positive offsets to active inputs (biased to 90% of trip level) and without $\Delta p$ compensation (via relay #11). |
| 9 | Two channels ($A_a$ & $B_1$) with opposing offsets to active inputs (channel A biased positively and channel B active input biased negatively to 90% trip level). |

*Subscripts: a - active, 1 - first backup, 2 - second backup

TABLE 28 (cont'd)

TEST CONDITIONS

| Test Condition | Test Condition Description |
|---|---|
| 10 | One channel ($B_a$) with hydraulic pressure reduced to 2000 psi.* |
| 11 | Two channels ($A_a$ & $C_1$) with hydraulic pressure reduced to 2000 psi. |

Baseline data will be recorded under the above conditions.

FAILURE TRANSIENTS

| | |
|---|---|
| 12 | Positive hardover sequentially applied to channels $A_a$, $B_1$ & $C_2$ command inputs with other inputs at null. |
| 13 | Positive hardover sequentially applied to channels $B_a$, $A_2$ & $C_1$ command inputs with other inputs at null. |
| 14 | Positive hardover sequentially applied to channels $C_a$, $B_1$ & $A_2$ command inputs with other inputs at null. |
| 15 | Slowover + input sequentially applied to channels $A_a$, $B_1$ & $C_2$ with other inputs at null. |
| 16 | Slowover - input sequentially applied to channels $A_a$, $B_1$ & $C_2$ with other inputs at null. |
| 17 | Slowover + input sequentially applied to channels $B_a$, $A_1$ & $C_2$ with other inputs at null. |
| 18 | Slowover - input sequentially applied to channels $B_a$, $A_1$ & $C_2$ with other inputs at null. |
| 19 | Slowover + input sequentially applied to channels $C_a$, $B_1$ & $A_2$ with other inputs at null. |
| 20 | Slowover - input sequentially applied to channels $C_a$, $B_1$ & $A_2$ with other inputs at null. |

*Subscripts: a - active, 1 - first backup, 2 - second backup.

TABLE 28 (cont'd)

TEST CONDITIONS

| Test Condition | Test Condition Description |
|---|---|
| | FAILURE TRANSIENTS |
| 21 | Open coil failure of active path servovalve sequentially applied to channels $A_a$, $B_1$ & $C_2$ with system cycling at 1.0 Hz.* |
| 22 | Open coil failure of active path servovalve sequentially applied to $B_1$ & $C_2$ with system cycling at 1.0 Hz. |
| 23 | Open coil of active path servovalve sequentially applied to channels $B_1$, $C_2$ & $A_a$ with null input. |
| 24 | Open actuator position feedback of model path sequentially applied to $A_a$, $B_1$ & $C_2$ with system cycling @ 1 Hz. |
| 25 | Open actuator position feedback of model path sequentially applied to $B_1$ & $C_2$ with system cycling @ 1 Hz. |
| 26 | Simultaneous grounding of inputs (command and model) to channels $A_a$, $B_1$ & $C_2$ with system operating at 10 Hz with maximum unsaturated amplitude. |
| 27 | Simultaneous positive hardover inputs (+10V) sequentially applied to the command and model inputs of channels $A_a$, $B_1$ & $C_2$ with the system biased to 50% extend. |
| 28 | Simultaneous negative hardover inputs (-10V) sequentially applied to the command and model inputs of channels $A_a$, $B_1$ & $C_2$ with the system biased to 50% extend. |
| 29 | Simultaneous positive hardover inputs (+10V) sequentially applied to the command and model inputs of channels $A_a$, $B_1$ & $C_2$ with system operating at 10 Hz at maximum unsaturated amplitude. |
| 30 | Simultaneous negative hardover inputs (-10V) sequentially applied to the command and model inputs of channels $A_a$, $B_1$ & $C_2$ with the system operating at 10 Hz at maximum unsaturated amplitude. |

*Subscripts: a - active, 1 - first backup, 2 - second backup.

## 5.5 Test Results

### 5.5.1 General

In order to reduce the volume of test data presented in this section, the majority of the performance measurement data has been reduced to tabulated form. Since the time response characteristics are not well defined by listing just one or two characteristic parameters, the step response measurements and the failure transient measurements are presented graphically as recorded. The following results are presented in tabulated form for Conditions 1 through 11.

1. Static Threshold
2. Dynamic Threshold
3. Frequency Response
4. Distortion
5. Hysteresis
6. Saturation Velocity

For these test results which have been reduced to table form, a sample of the data recorded is included with each table. In addition to the tabulated performance characteristics listed above, linearity and extend and retract step responses for Conditions 1 and 11 are presented as recorded in graphical form.

In presenting the measurements of threshold and hysteresis, the results are given both in percent of the input for full servovalve output flow. Presenting the percentage hysteresis in terms of both these inputs describes the threshold and hysteresis characteristics in terms which allow comparing different control mechanizations independent of the actuator stroke sizing.

The test results presented for the active/on-line mechanization are presented in the following order:

1. Performance measurement for Conditions 1 through 11
2. Failure transients for Conditions 1 through 11
3. Failure logic detection characteristics

### 5.5.2 Performance Measurements

#### 5.5.2.1 Static Threshold

Figure 157 shows the data recorded in establishing the static threshold for Condition 1. Note that the .1 Hz ramp input is slowly increasing in amplitude with increasing time. The threshold value is determined by the first input amplitude where the actuator output starts to respond to the control input. The high frequency noise content of the output signal is made up of background noise picked up by the instrumentation lines to the recorder. The edge of the noise shows the actuator responding to the .1 Hz input ramp. Table 29 shows t': static threshold values measured for test Conditions 1 through 11.

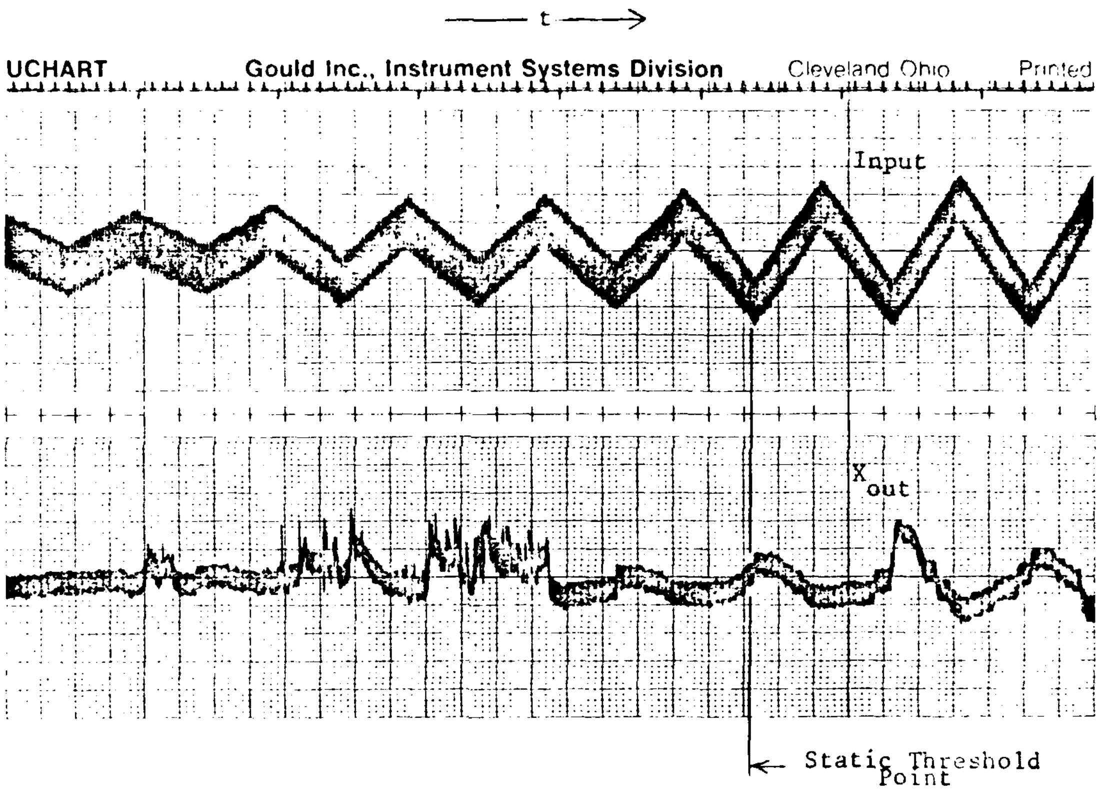
From Table 29, it is apparent that the static threshold remains below 4% of the input level for maximum flow from the servovalves. This is considerably better than that measured on the Bertea Force Sharing System described previously in this report. The threshold measurements above 3% of the input for maximum flow from the servovalves occurred for test conditions 6a, 7a and 11. These test conditions correspond to two input offset conditions (Conditions 6a and 7a) and a reduction of hydraulic pressure to two channels (Condition 11).

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - National Water Lift Unit

Date Prepared 4/24/79

TEST - Static Threshold - Condition 1




0.1 Hz Ramp Input

Scale: Input = 0. 001 v/div

$X_{out}$ = 0.00006 in/div

t = 2 div/sec

FIGURE 157 Static Threshold - Condition 1

TABLE 29

Static Threshold

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 4/18/79

TEST ITEM - Grumman - National Water Lift Unit

TEST - STATIC THRESHOLD

| Test Condition | Input Volts | Static Threshold % of Max Input | Static Threshold % of $E_v$ Max |
|---|---|---|---|
| 1 | 0.015 | 0.08 | 2.34 |
| 2 | 0.018 | 0.09 | 2.81 |
| 3 | 0.007 | 0.03 | 1.02 |
| 4 | 0.012 | 0.06 | 1.75 |
| 5 | 0.013 | 0.06 | 1.95 |
| 6 | 0.010 | 0.05 | 1.56 |
| 6a | 0.025 | 0.13 | 3.91 |
| 7 | 0.014 | 0.07 | 2.19 |
| 7a | 0.022 | 0.11 | 3.44 |
| 8 | 0.0112 | 0.06 | 1.80 |
| 8a | 0.010 | 0.06 | 1.56 |
| 9 | 0.011 | 0.06 | 1.72 |
| 10 | 0.018 | 0.09 | 2.81 |
| 11 | 0.026 | 0.13 | 3.98 |

Since the pressure feedback used to defeat the driving force capability of the on-line control channels was rolled off by the low pass filter used in the feedback path, the active and on/line channels all contributed to the driving force requirements at the 10 Hz input frequency used for the dynamic threshold tests.

Under this condition, the control channels operate on a pure force sharing basis. From the test results it appears that with the high pressure gain valves there is a force fight between channels which reduces the dynamic pressure gain, resulting in a greater dynamic than static threshold.

The other possible cause of the higher dynamic threshold is that the dynamic flow requirement associated with the hydraulic control circuit requires enough flow at 10 Hz to significantly reduce the pressure gain of the control valves. The reduced dynamic pressure gain results in the higher dynamic threshold.

The measured increase in dynamic threshold over the static threshold for all test conditions is probably a result of a combination of both of the preceding phenomena.

The percent threshold measured for the 10 Hz input test conditions are considerably lower than that measured on the Bertea Force Sharing System (by a factor of at least two for the same test conditions). This demonstrates that the active-on-line system has better small signal response characteristics than the previously tested force sharing system.

5.5.2.2 Dynamic Threshold

Figure 158 shows the data recorded in establishing the dynamic threshold for Condition 1. A 10 Hz sine wave input was used to command the test system. This frequency was approximately .5 of the bandpass frequency at which the - 3 DB amplitude response occurred. As shown on Figure 158, the input amplitude of the driving frequency was gradually increased with increasing time. The bottom trace shows the start of the actuator response to the input signal.

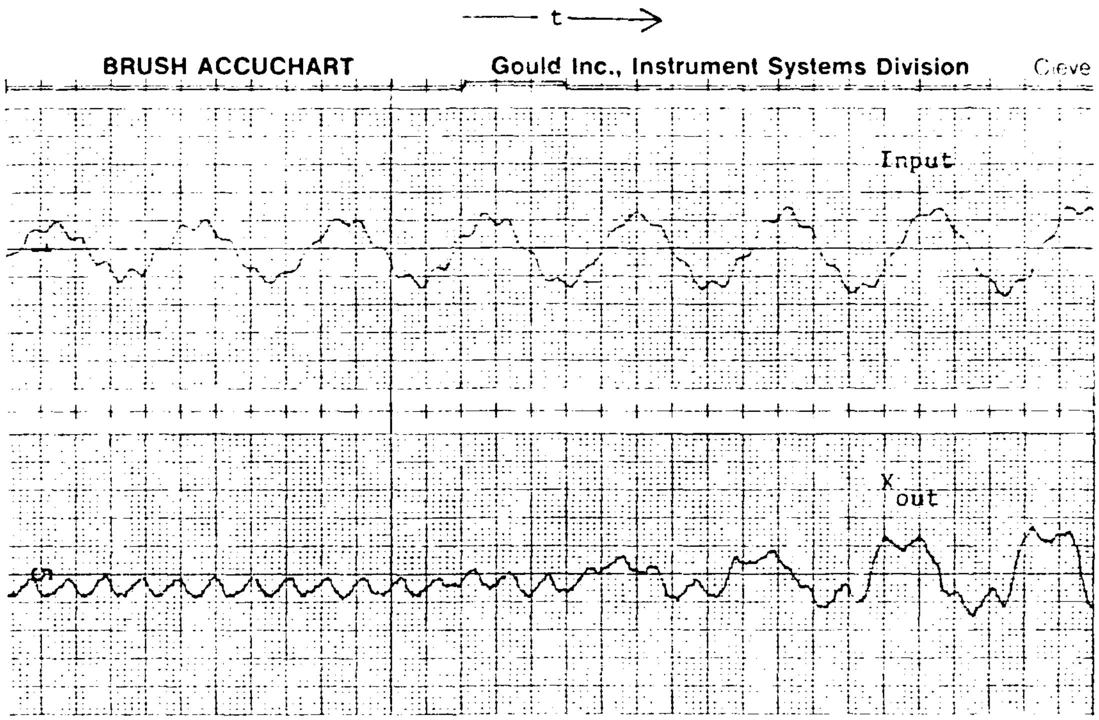
Table 30 shows the dynamic threshold measurements for Conditions 1 through 11. Compared to the static threshold measurements listed on Table 29, the dynamic threshold measurements are considerably greater, by a factor of 4 for some test conditions. This was not anticipated, since the sinusoidal input to the system generally serves to reduce the dynamic threshold compared to the static threshold in a single channel electro-hydraulic system. The dynamic threshold measured greater than 10% of the $E_v$ max input level for test Conditions 2, 5, 8, 9, and 11. Test Conditions 2 and 5 are with one or more channels failed and bypassed. Since the bypassed channels have to be moved by the remaining unfailed channels, some increase from the normal operating condition (Condition 1) is expected. The increase from the 9.38% threshold value of Condition 1 is not particularly great for test Conditions 2 and 5, although the threshold with two channels failed did reach a value 50% greater than the threshold measured for test Condition 1. Test Conditions 8, 9 and 11 are with offset inputs to the control channels. For these test conditions, the dynamic threshold increased approximately 17%.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - National Water Lift Unit

Date Prepared 4/25/79

TEST - Dynamic Threshold - Condition 1




10.0 Hz Sine Wave Input

Scale:
Input = 0.005 v/div
$X_{out}$ = 0.00006 in/div
t = 200 div/sec

FIGURE 158 Dynamic Threshold - Condition 1

TABLE 30

Dynamic Threshold

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 4/18/79

TEST ITEM - Grumman - National Water Lift Unit

TEST - DYNAMIC THRESHOLD

| Test Condition | Input Volts | Dynamic Threshold | |
|---|---|---|---|
| | | % of Max Input | % of $E_v$ Max |
| 1 | 0.060 | 0.30 | 9.38 |
| 2 | 0.065 | 0.33 | 10.16 |
| 3 | 0.053 | 0.26 | 3.91 |
| 4 | 0.055 | 0.28 | 8.59 |
| 5 | 0.095 | 0.48 | 14.84 |
| 6 | 0.060 | 0.30 | 9.38 |
| 6a | 0.030 | 0.15 | 4.69 |
| 7 | 0.050 | 0.25 | 7.81 |
| 7a | 0.013 | 0.07 | 2.03 |
| 8 | 0.070 | 0.35 | 10.94 |
| 8a | 0.013 | 0.08 | 2.03 |
| 9 | 0.070 | 0.35 | 10.94 |
| 10 | 0.030 | 0.15 | 4.69 |
| 11 | 0.070 | 0.35 | 10.94 |

5.5.2.3 Frequency Response

Figure 159 shows the frequency response recorded for the Condition 1 frequency response measurement. The response for all test conditions resembled the Condition 1 response in terms of lack of peaking and the roll-off slopes. Zero Db on Figure 159 corresponds to an input amplitude of 10% of that required for maximum actuator output stroke. This test input level met the criteria of not producing observable output waveform distortion due to threshold or saturation effects over the recorded frequency range.

Table 31 lists the frequency response for Conditions 1 through 11 in terms of the frequency at which the -90 degree phase angle and the -3 Db amplitude ratio points occurred for each test condition. For all test conditions, the frequency associated with the -3 Db amplitude ratio remained relatively constant. The range of variation of the frequency corresponding to the -3 Db point was from 23 Hz for the normal operating condition of Condition 1 to 19 Hz for Condition 5 with two channels hydraulically failed. The range of the frequency associated with the -90 degree phase angle was from 22 Hz for Condition 5 to 35 Hz for Condition 7. The offset input test conditions gave the highest frequencies corresponding to the -90 degree phase angle.

The baseline response of Condition 1 was the condition having the highest amplitude response (-3 Db frequency at a frequency greater than all other test conditions). The phase angle change characteristic of the response measurement indicated a change in the damping of the response with the different test conditions.

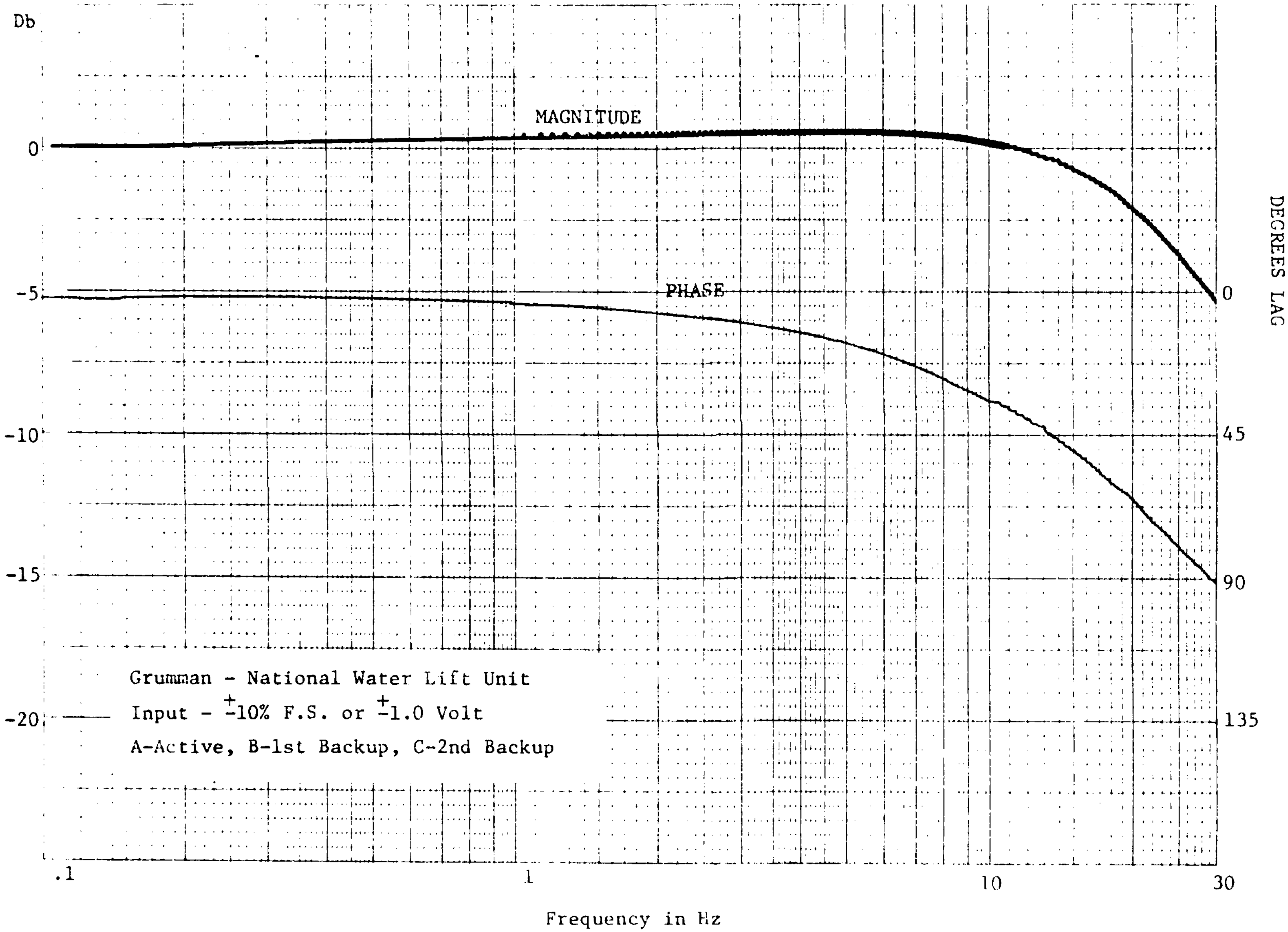



FIGURE 159 Frequency Response - Condition 1

TABLE 31

Frequency Response

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 4/18/79

TEST ITEM - Grumman - National Water Lift Unit

TEST - FREQUENCY RESPONSE

| Test Condition | Output 4% Full Scale -3 db Hz | $-90^{o}$ Hz |
|---|---|---|
| 1 | 23.0 | 29.0 |
| 2 | 22.0 | 27.5 |
| 3 | 20.0 | 25.0 |
| 4 | 22.0 | 27.0 |
| 5 | 19.0 | 22.0 |
| 6 | 22.0 | 34.5 |
| 6a | 22.0 | 34.0 |
| 7 | 22.0 | 35.0 |
| 7a | 19.5 | 34.0 |
| 8 | 22.0 | 34.0 |
| 8a | 20.0 | 34.5 |
| 9 | 21.0 | 34.0 |
| 10 | 19.5 | 28.0 |
| 11 | 20.0 | 26.0 |

5.5.2.4 Distortion

Table 32 lists the harmonic distortion measurements for test Conditions 1 through 11. The table lists the distortion measurements in terms of the % distortion value difference between each particular test condition and the value measured for Condition 1. Note that the distortion measurements at three different frequencies are given. These frequencies correspond to 25%, 50% and 100% of the actuator bandpass frequency. Note that the baseline harmonic distortion values for Condition 1 are below 2%. These baseline distortion values are less than 61% of those measured on the Bertea Force Sharing System for the same test condition and the corresponding three frequencies. Table 32 does not list distortion measurements for test Conditions 6a, 7a and 8a. These test conditions were not used during the particular test sequence.

The distortion change from the baseline value was below a difference of 1% distortion for many of the test conditions. The distortion increased most for the test conditions of one or two channel failed (Conditions 3, 4 and 5). For the test conditions with a null offset (Conditions 5 through 11) there was a reduction of the distortion at the 5 Hz test frequency and only small increase (except for Condition7) in the % distortion at 10 and 20 Hz.

The increase in distortion with channel failures is due to the loss of driving force capability with the loss of each channel. The change of distortion with the different test conditions was somewhat greater than that previously measured on the Bertea Force Sharing System. However, the distortion characteristics remained commendably low for all the operating conditions and indicated that the ability of the test system to reproduce the input signal over the frequency bandpass of the system was very good.

TABLE 32

Distortion

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 4/19/79

TEST ITEM - Grumman - National Water Lift Unit

TEST - DISTORTION

| Test Condition | Change of % distortion from baseline value | | |
|---|---|---|---|
| | % @ 5 Hz | % @ 10 Hz | % @ 20 Hz |
| 1 | Baseline Value* | Baseline Value** | Baseline Value*** |
| 2 | +0.26 | +0.60 | +0.15 |
| 3 | +1.91 | +2.55 | +2.40 |
| 4 | +1.41 | +0.05 | +0.60 |
| 5 | +3.51 | +3.45 | +0.20 |
| 6 | -0.94 | +0.45 | +0.20 |
| 6a | | | |
| 7 | -0.89 | +2.58 | +2.23 |
| 7a | | | |
| 8 | -0.86 | +0.43 | +0.18 |
| 8a | | | |
| 9 | -0.96 | +0.43 | +0.13 |
| 10 | -0.77 | +0.19 | -0.32 |
| 11 | -0.46 | +0.18 | +0.33 |

*1.74% **0.90% ***1.65%

### 5.5.2.5 Hysteresis

Figure 160 shows the data recorded in measuring the hysteresis of the mechanization for Condition 1. The input level used was ± 1% of the input for full actuator position.

Table 33 lists the hysteresis measured for test Conditions 1 through 11 in terms of the actuator full scale input and also in terms of the input required to generate full flow from the servovalves. The hysteresis in terms of the input for the maximum actuator stroke is less than .25% for all test conditions. The measured results expressed in terms of the actuator stroke are quite similar in range (.98 to .22%) to those measured on Configuration A of the Bertea Force Sharing System (.095 to .21%). However, the worst case of hysteresis is expressed in terms of the input for full flow from the servovalves is 6.88% for the active/on-line system versus 27.3% for the Configuration A force sharing system. This comparison illustrates the advantage of expressing hysteresis in terms of the control valve maximum input as well as the control system maximum input.

As listed on Table 33, the hysteresis for the active/on-line system remains between 2.5% and 6.88% of the maximum input for full servovalve flow for all test conditions. Condition 2, with one channel electrically failed, gave the greatest hysteresis reading. Condition 8, with two channels having a negative offset input, gave the lowest reading. The hysteresis values measured compare favorably with a conventional electrohydraulic actuator and are better than the previously evaluated force sharing system.

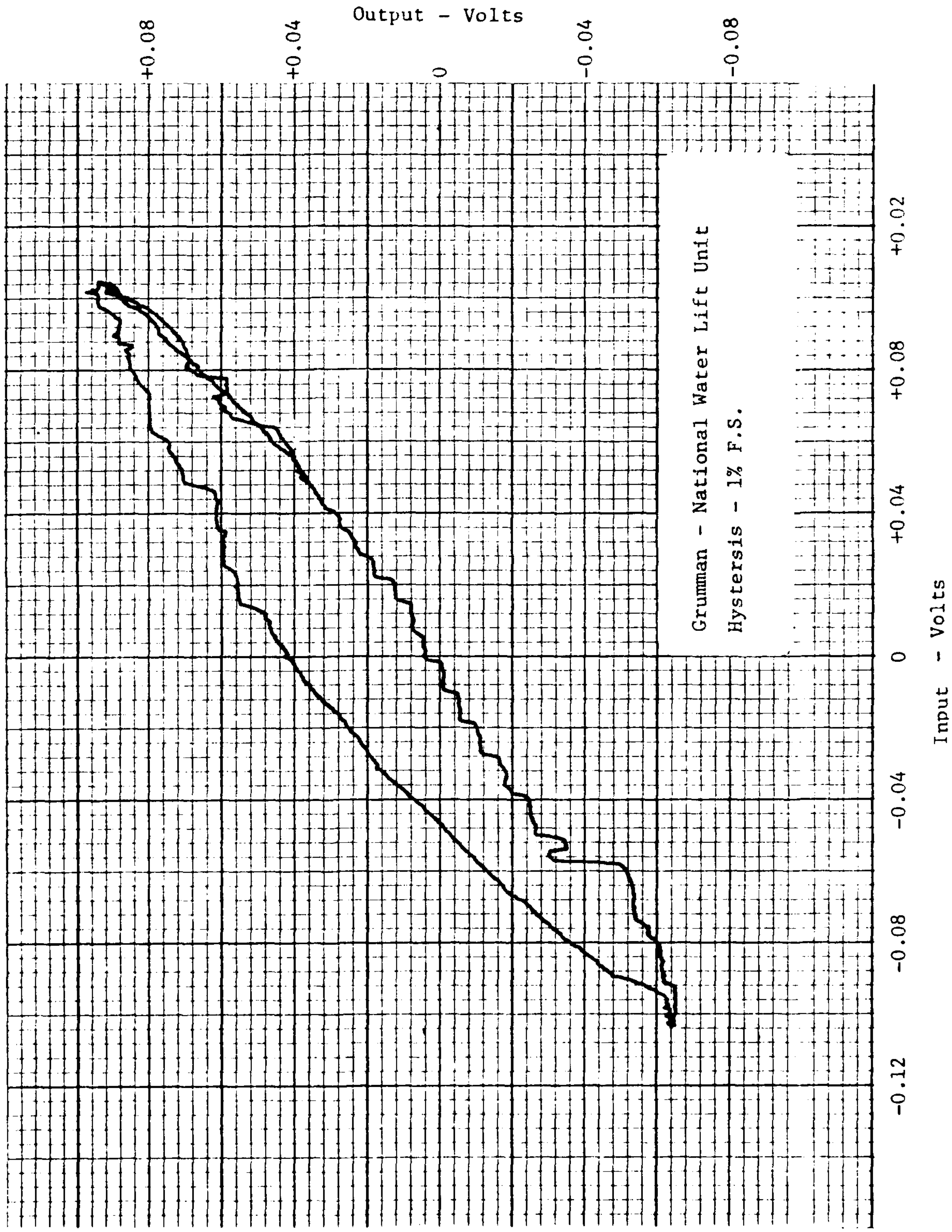

Output - Volts
+0.08
+0.04
0
-0.04
-0.08
Grumman - National Water Lift Unit
Hysteresis - 1% F.S.
+0.02
+0.08
+0.04
0
-0.04
-0.08
-0.12
Input - Volts

TABLE 33

Hysteresis

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 4/19/79

TEST ITEM - Grumman - National Water Lift Unit

TEST - HYSTERESIS

| Test Condition | % Full Scale | % of $E_v$ Max |
|---|---|---|
| 1 | 0.16 | 5.00 |
| 2 | 0.22 | 6.88 |
| 3 | 0.19 | 5.94 |
| 4 | 0.18 | 5.63 |
| 5 | 0.18 | 5.63 |
| 6 | 0.09 | 2.81 |
| 6a | 0.40 | 3.75 |
| 7 | 0.10 | 3.13 |
| 7a | | |
| 8 | 0.08 | 2.50 |
| 8a | | |
| 9 | 0.10 | 3.13 |
| 10 | 0.18 | 5.63 |
| 11 | 0.15 | 4.69 |

5.5.2.6 Saturation Velocity

Figure 161 shows the data recorded for test Condition 1 in order to determine the saturated velocity of the test system output. Both the extend and the retract time traces for a step input of 8.4 volts applied to the input of the test system are shown. The input amplitude of the step was large enough to generate maximum flow from the servovalves to the actuator.

Table 34 lists the saturated extend and retract velocities measured for test Conditions 1 through 11. Some variation in the measured velocity compared to that of the normal operating condition (Condition 1) occurred for each test condition. The saturated velocity was not less than 5.00 in/sec for any test condition, which compared favorably with the 5.58 in/second (extend direction) for the normal operating system.

Note that the actuator output velocity for test conditions with one or more channels failed (Conditions 2 through 5) changed very little from that of the normal operating system (Condition 1).

5.5.2.7 Linearity

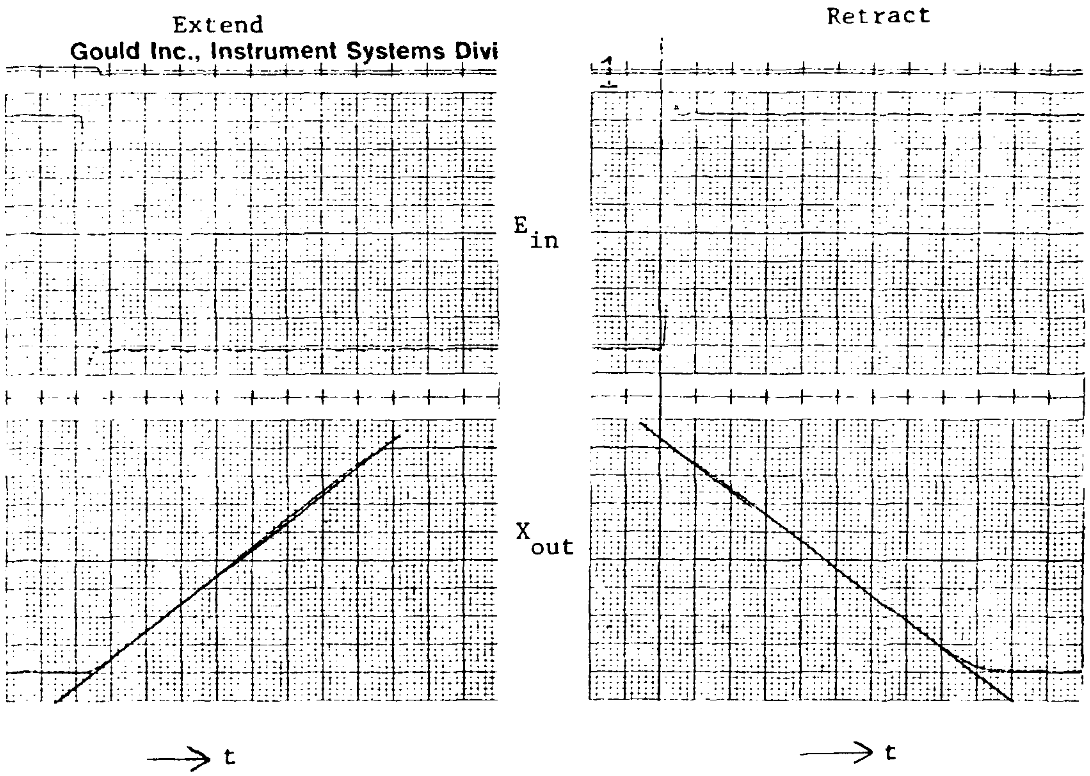
Figure 162 shows the actuator output linearity measured for Condition 1. The linearity of the mechanization is primarily determined by the feedback transducers associated with each control channel and the loop gains of the individual channels. The linearity measured for all the operating conditions was essentially the same as that shown on Figure 162 and was within 1% full scale.

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM – Grumman – National Water Lift Unit

Date Prepared 4/25/79

TEST – Saturation Velocity – Condition 1




Maximum Amplitude Step Input

Scale: Input = 0.200 v/div

$X_{out}$ = 0.013 in/div

t = 200 div/sec

FIGURE 161 Saturation Velocity – Condition 1

TABLE 34

Saturation Velocity

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 4/19/79

TEST ITEM - Grumman - National Water Lift Unit

TEST - SATURATION VELOCITY

| Test Condition | Extend - in./sec. | Retract - in./sec. |
|---|---|---|
| 1 | 5.58 | 5.85 |
| 2 | 5.45 | 6.00 |
| 3 | 5.58 | 5.93 |
| 4 | 6.32 | 6.67 |
| 5 | 5.85 | 5.85 |
| 6 | 5.45 | 5.58 |
| 6a | 7.21 | 6.59 |
| 7 | 5.85 | 6.15 |
| 7a | 5.85 | 5.39 |
| 8 | 5.58 | 5.85 |
| 8a | 6.15 | 5.85 |
| 9 | 5.71 | 6.15 |
| 10 | 5.33 | 5.71 |
| 11 | 5.00 | 5.45 |

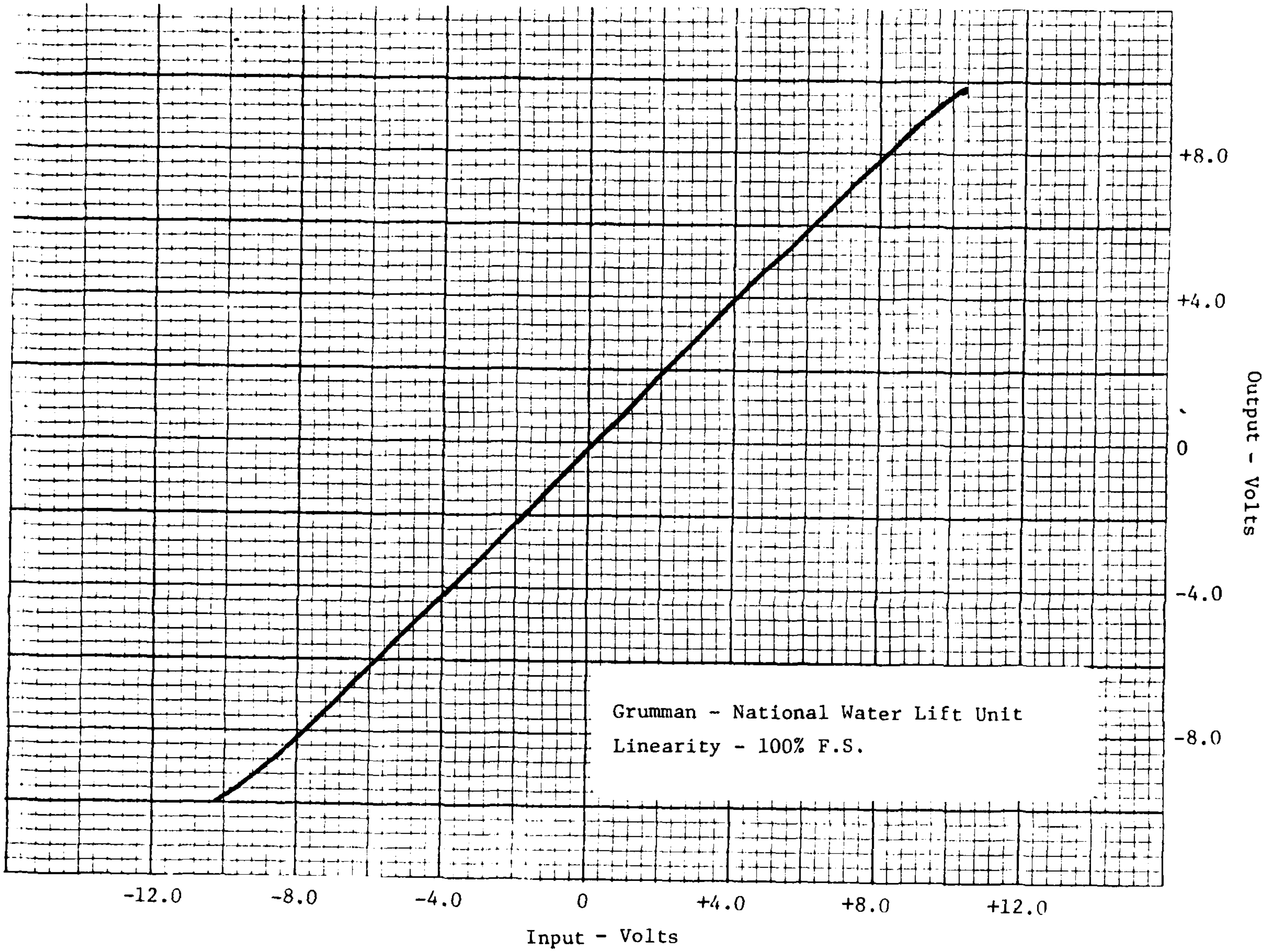



FIGURE 162 Linearity - Condition 1

#### 5.5.2.8 Step Response

Figures 163 through 170 show the extend and retract step response measurements for Conditions 1 through 11. The input level for these measurements was 10% of the input for maximum actuator position. This level, since the input was a step, was twice that required for saturation of the servovalve. Therefore, until the actuator moved 50% of the total movement in response to the commanded step, the servovalve was saturated and the actuator moved at a saturation rate. The remaining 50% of the movement as shown on Figures 163 through 170 was unsaturated and indicates the transient response of the mechanization.

The measured response is consistent with the frequency response measurements. The step response shows no overshoot and no ringing for any of the test condition. The step response resembles that of a second order system with a damping ratio of approximately 1.

### 5.5.3 Failure Transients

Test Conditions 12 through 28 were used to establish the failure transient characteristics of the active/on-line system. The test results and the test conditions are arranged in the following order:

| TEST | Test Conditions |
|---|---|
| Electrical Hardover Input Transient (with actuator initially at rest) | 12, 13, 14 |
| Electrical Slowover Input Transient | 15, 16, 17, 18, 19, 20 |
| Open Servovalve Coil Transient (with actuator cycling) | 21, 22 |
| Open Servovalve Coil Transient (with actuator at null) | 23 |
| Open Actuator Position Feedback (with actuator at null) | 24, 25 |
| Simultaneous Input transients | 26, 27, 28, 29, 30 |

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - National Water Lift Unit

TEST - Step Response - Conditions 1 & 2

Date Prepared 4/30/79

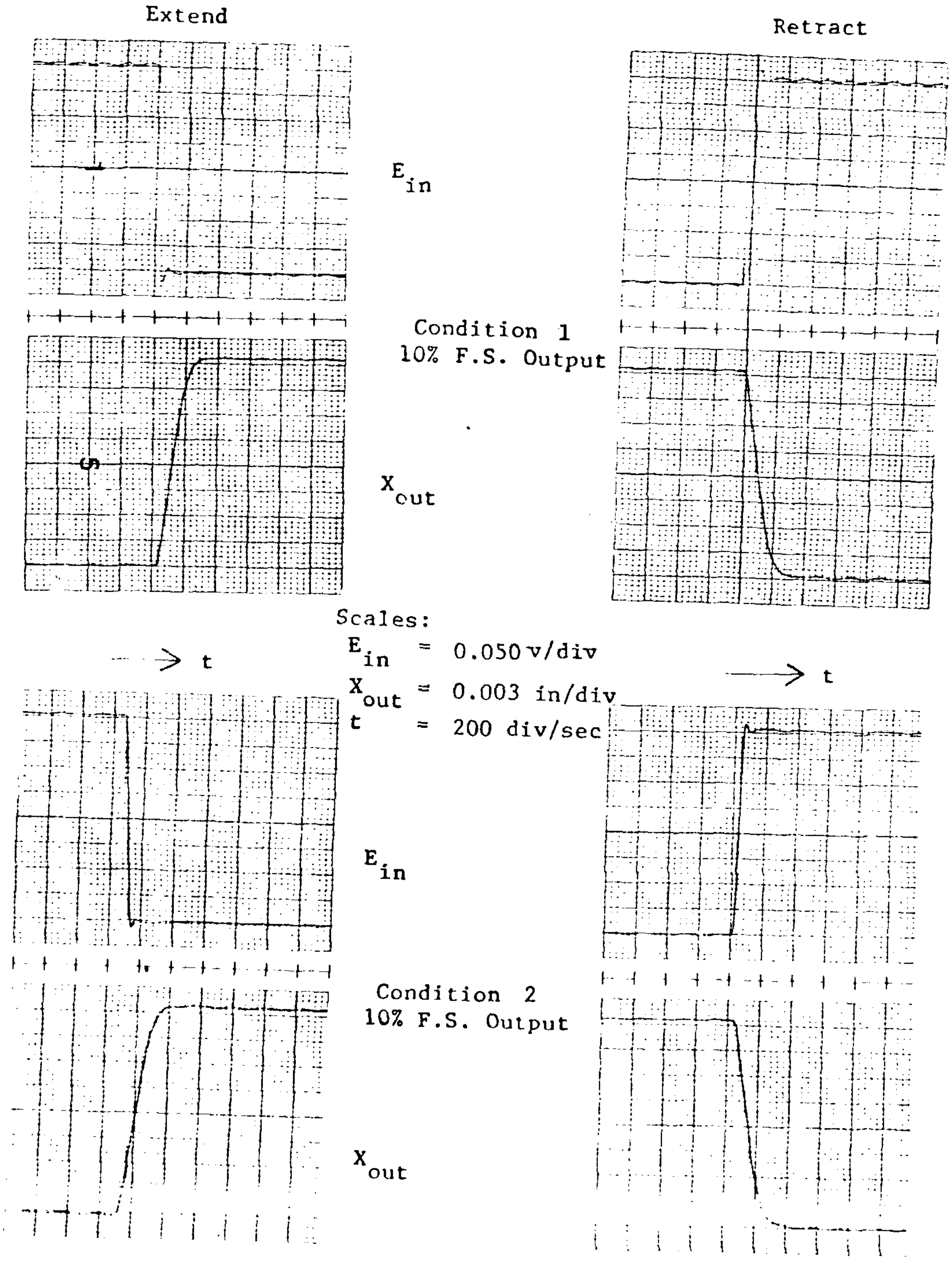



FIGURE 163 Step Response - Conditions 1 & 2

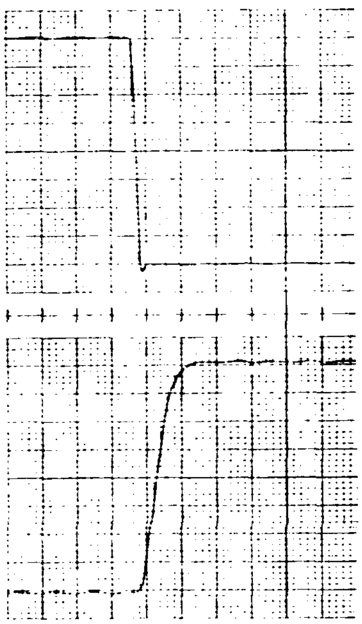
DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - National Water Lift Unit

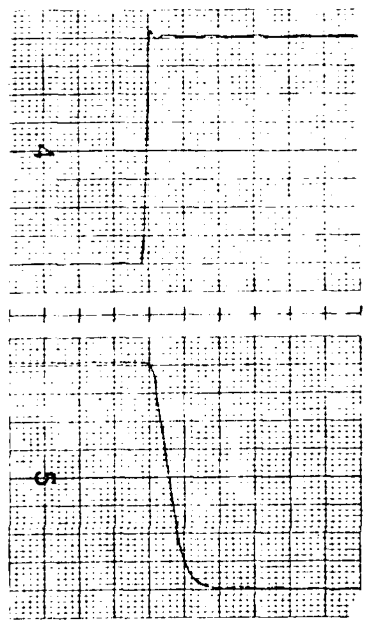
Date Prepared 4/30/79

TEST - Step Response - Conditions 3 & 4

Extend



Retract



$E_{in}$

Condition 3
10% F.S. Output

$X_{out}$

→ t

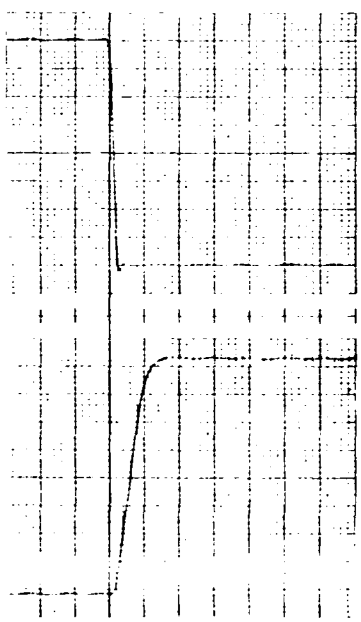
Scales:

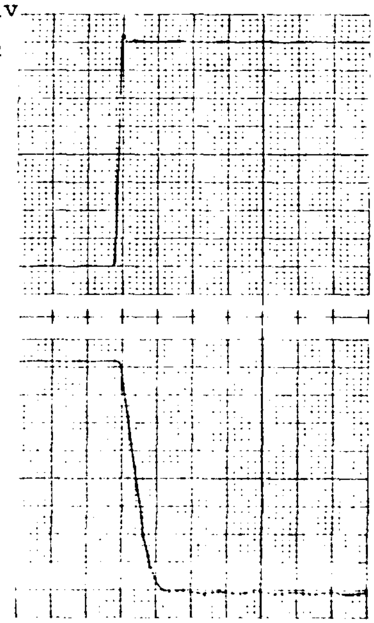
$E_{in}$ = 0.050 v/div

$X_{out}$ = 0.003 in/div

t = 200 div/sec

→ t





$E_{in}$

Condition 4
10% F.S. Output

$X_{out}$

FIGURE 164 Step Response - Conditions 3 & 4

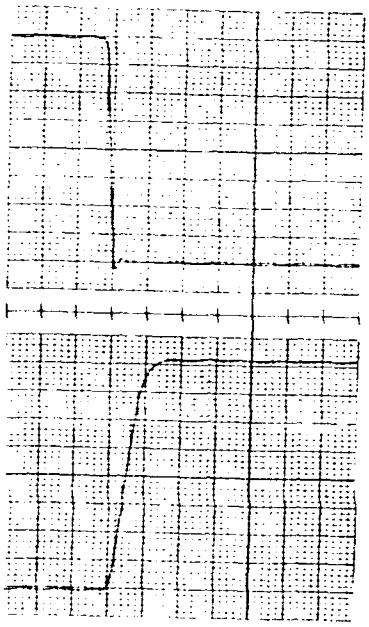
DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - National Water Lift Unit

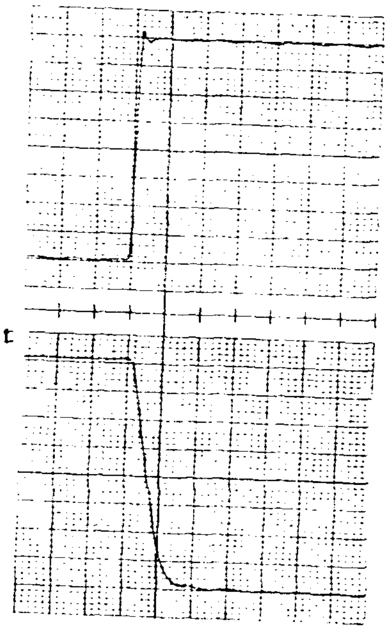
TEST - Step Response - Condition 5

Date Prepared 4/30/79

Extend



Retract



$E_{in}$

Condition 5
10% F.S. Output

$X_{out}$

→ t

→ t

Scales:

$E_{in}$ = 0.050 v/div

$X_{out}$ = 0.003 in/div

t = 200 div/sec

FIGURE 165 Step Response - Condition 5

DYNAMIC CONTROLS, INC.
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TEST ITEM - Grumman - National Water Lift Unit

Date Prepared 4/30/79

TEST - Step Response - Conditions 6 & 6a

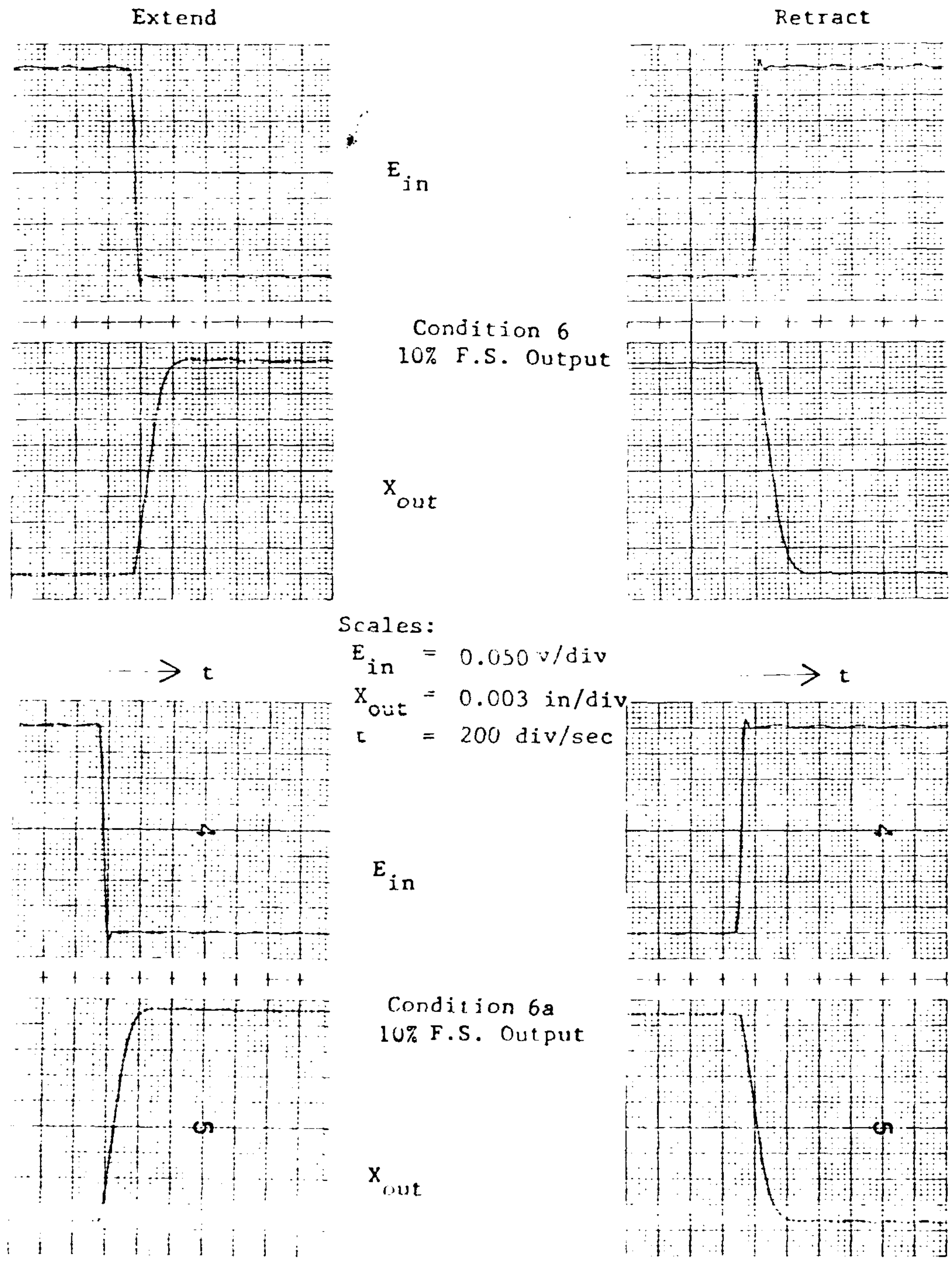



FIGURE 166 Step Response - Conditions 6 & 6a

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - National Water Lift Unit

Date Prepared 4/30/79

TEST - Step Response - Conditions 7 & 7a

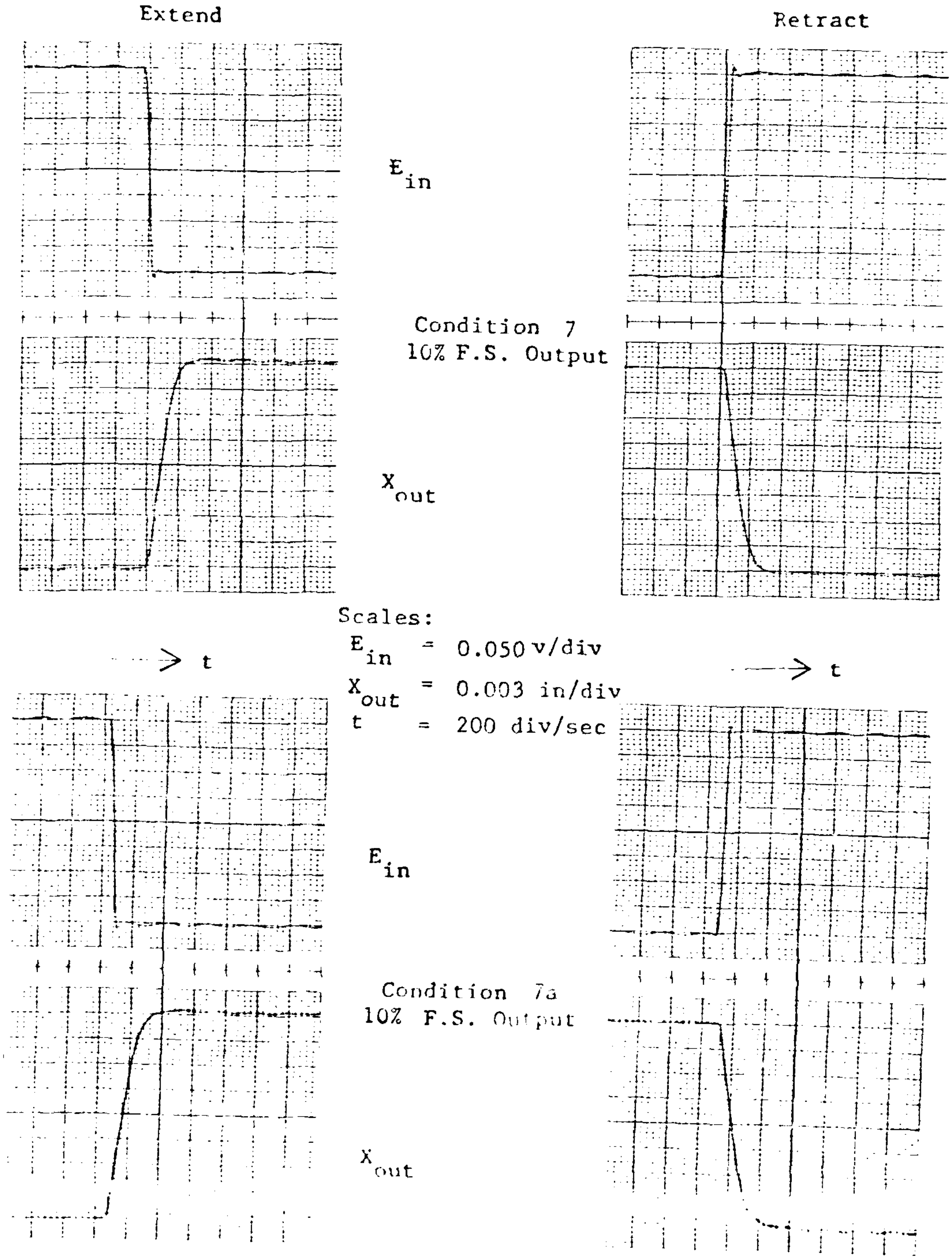



FIGURE 167 Step Response - Conditions 7 & 7a

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - National Water Lift Unit

Date Prepared 4/30/79

TEST - Step Response - Conditions 8 & 8a

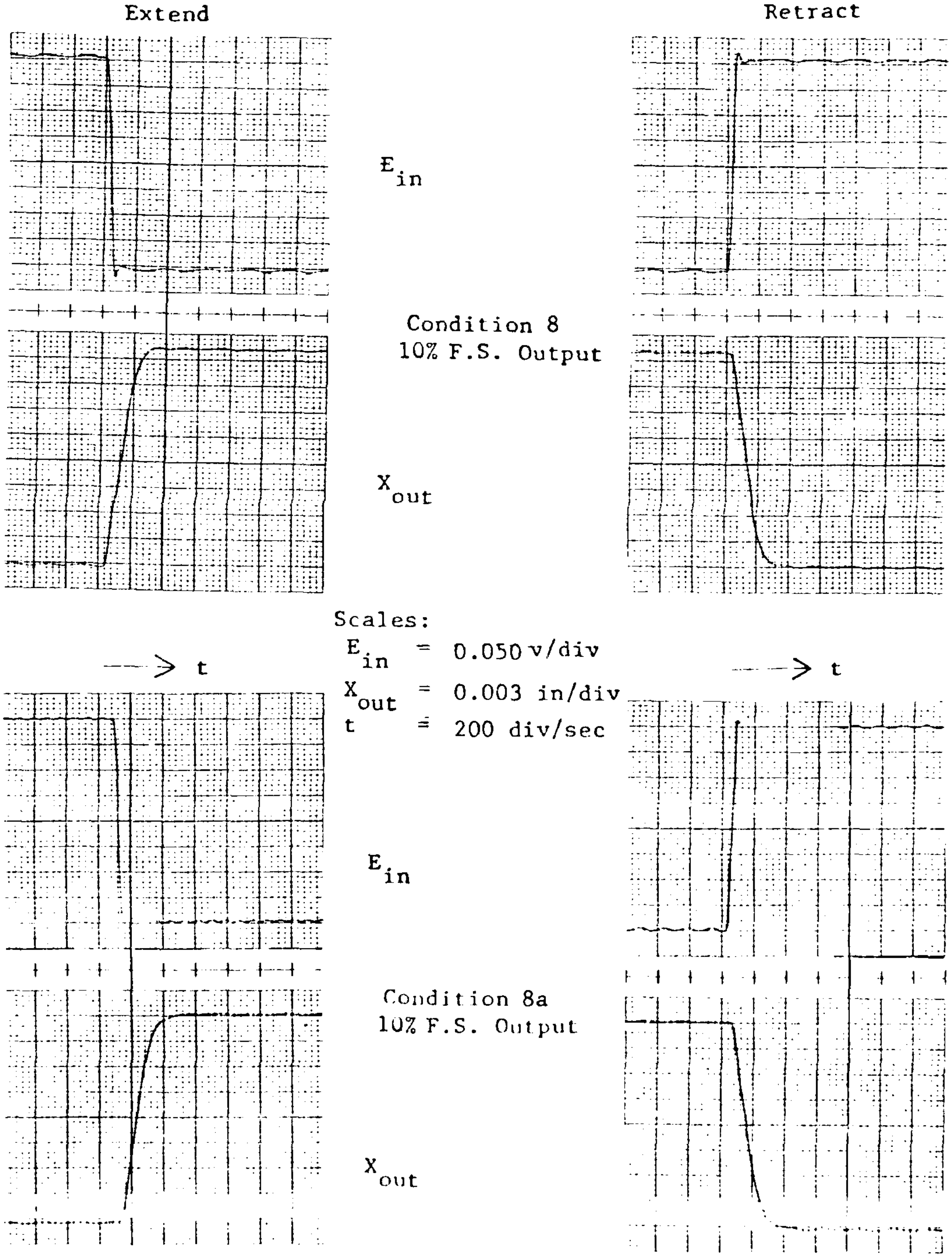



FIGURE 168 Step Response - Conditions 8 & 8a

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - National Water Lift Unit

Date Prepared 4/30/79

TEST - Step Response - Conditions 9 & 10

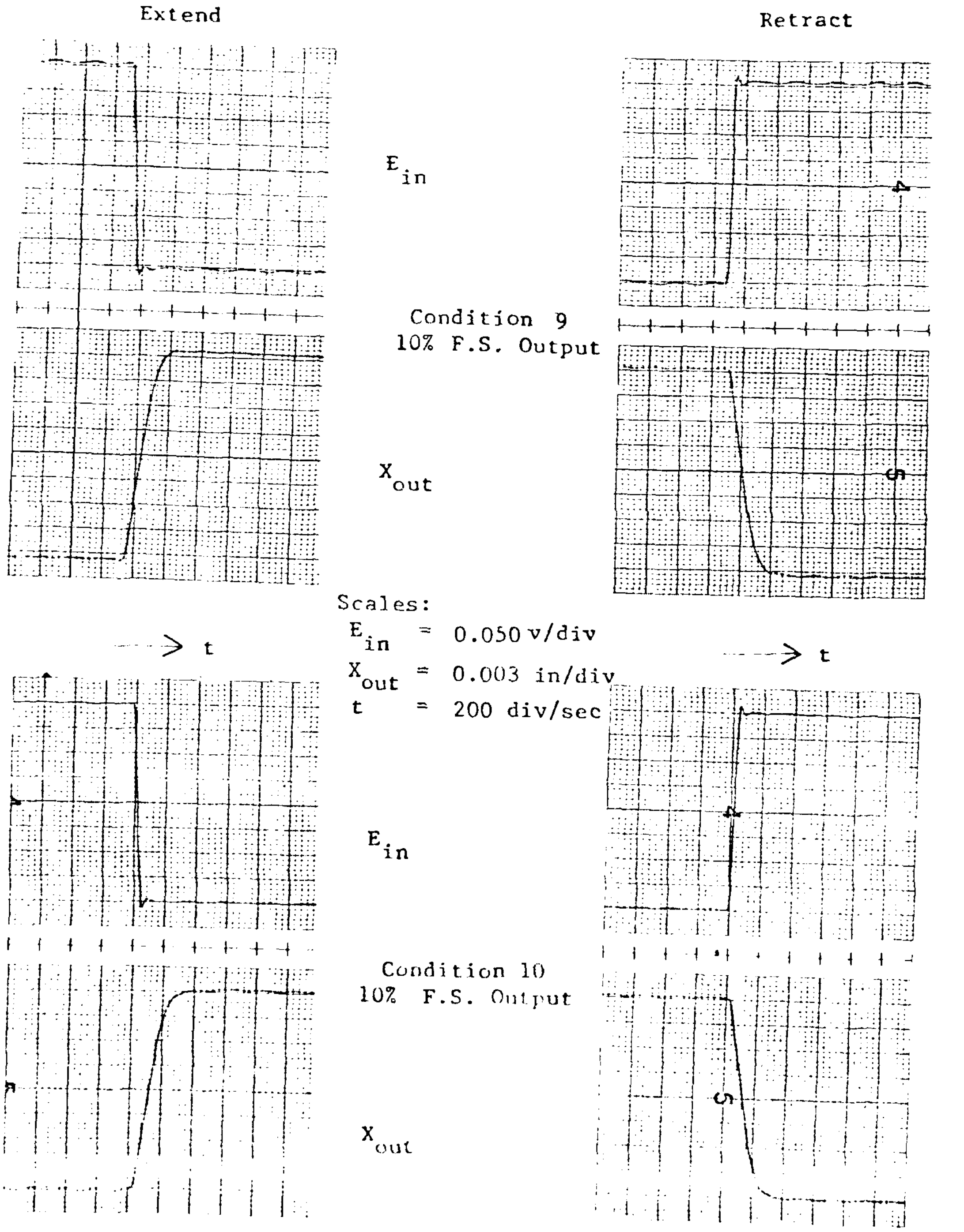



FIGURE 169 Step Response - Conditions 9 & 10

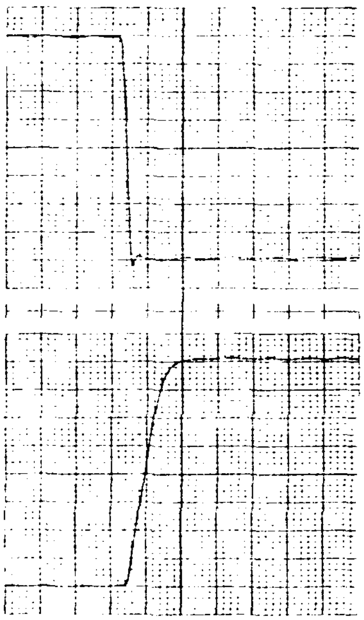
DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - National Water Lift Unit

Date Prepared 4/30/79

TEST - Step Response - Condition 11

Extend

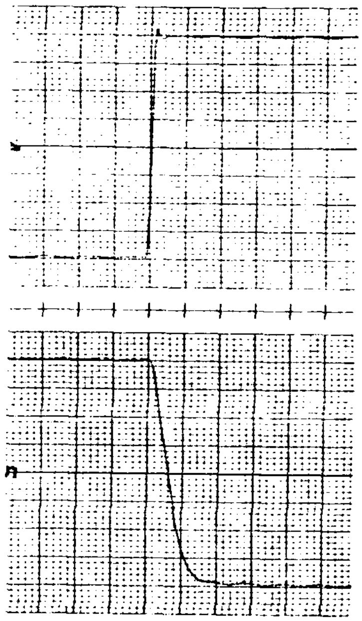


$E_{in}$

Condition 11
10% F.S. Output

$X_{out}$

Retract



Scales:

--> t

$E_{in}$ = 0.050 v/div

$X_{out}$ = 0.003 in/div

t = 200 div/sec

--> t

FIGURE 170 Step Response - Condition 11

Test Conditions 21 through 25 are intended to indicate the effect of failures detected by the servovalve comparator $K_1$ (Reference Figure 155). Test Conditions 12 through 20 and Conditions 24 and 25 are intended to indicate the effect of failures detected by the input comparator $K_4$ (Reference Figure 155). Test Conditions 26 through 30 are intended to show the effect of simultaneous input or feedback failures which would not be detected by either the input or servovalve failure logic comparators.

### 5.5.3.1 Electrical Hardover Input Transient

Figure 171 shows the effect of a + 10 volt hardover input applied sequentially to the command path input of channels A, B and C. As configured, channel A is initially the active channel and channel B and C are on-line. The output deviation of the system is 2.5% of the total actuator stroke with a time duration of the transient of .05 seconds. After the depressurization of channel A and the transfer of channel B to an active status, the actuator returns to the initial null position. Upon the second hardover input into channel B, the system output deviates 5.7% of the total actuator stroke for a duration of less than .05 seconds. The transient deviation for both the first and second hardover input are somewhat larger than that experienced with the Bertea Force Sharing System. However, the time duration of the transient with the active/on-line system is much shorter than that measured on the force sharing system (.05 seconds versus .85 seconds). Since the system would be used with a control actuator with a limited frequency response, that control actuator response to the shorter transient of the active/on-line system would be expected to be less than that of the force sharing system, even though the amplitude of the transient is greater than that of the force sharing system. The third input hardover into the command path input of channel C is detected by the active/on-line system and channel C is depressurized.

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Test Data

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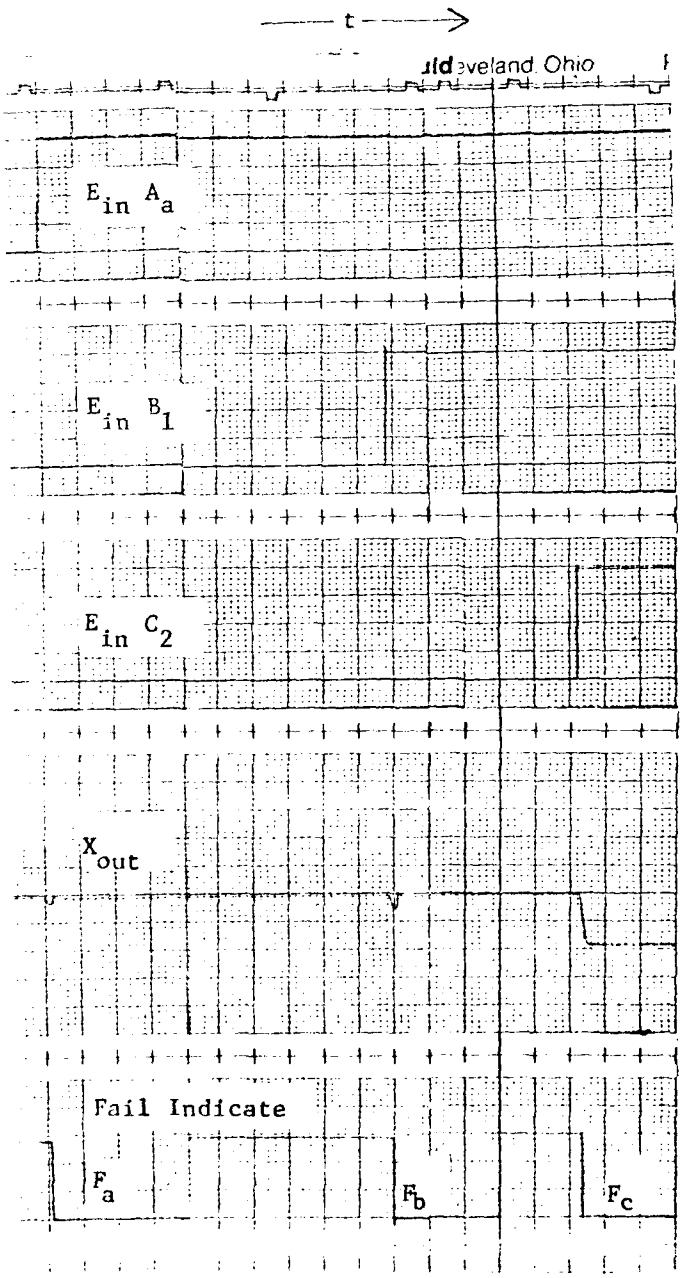
TEST - Failure Transients - Condition 28




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.030 in/div
t = 20 div/sec

FIGURE 171 Failure Transients - Condition 28

Figure 172 shows the effect of a hardover input applied sequentially to the command path input of channels A, B and C with the system configured with channel B the active channel and channels A and C the second and first on-line channels, respectively. This test condition shows the effect of the hardover input applied to other than the active channel as the first failure input. The system output does deviate with the first failure input, moving 2.5% of the total actuator stroke for total transient duration of .05 seconds.

For the second hardover input into the command path of channel B, the output deviation of the system is 6.25% of the total actuator stroke with a transient duration of .08 seconds. Note that channel B at the time the hardover was applied was operating in an active mode. The output deviations with the hardover inputs shown on Figure 172 are similar to those shown previously on Figure 171. This indicates that the hardover input creates the same first and second failure transients independent of whether the channel being failed is in the active or the on-line mode. The third hardover input failure applied to channel C is detected by the failure logic and channel C bypassed and depressurized.

Figure 173 shows the effect of applying hardover inputs into the command path of channels A, B and C with the channels initially configured with channel C the active channel and channels A and B the on-line channels. The deviation resulting from the first hardover input into channel A (which is operating in the on-line mode) is 2.5% of the total actuator stroke with a duration of .05 seconds. The second hardover input failure into channel B (which is operating in an on-line mode) is 5.3% of the maximum actuator stroke with a transient duration of .05 seconds. The third failure into the active channel A is detected and the channel depressurized and bypassed.

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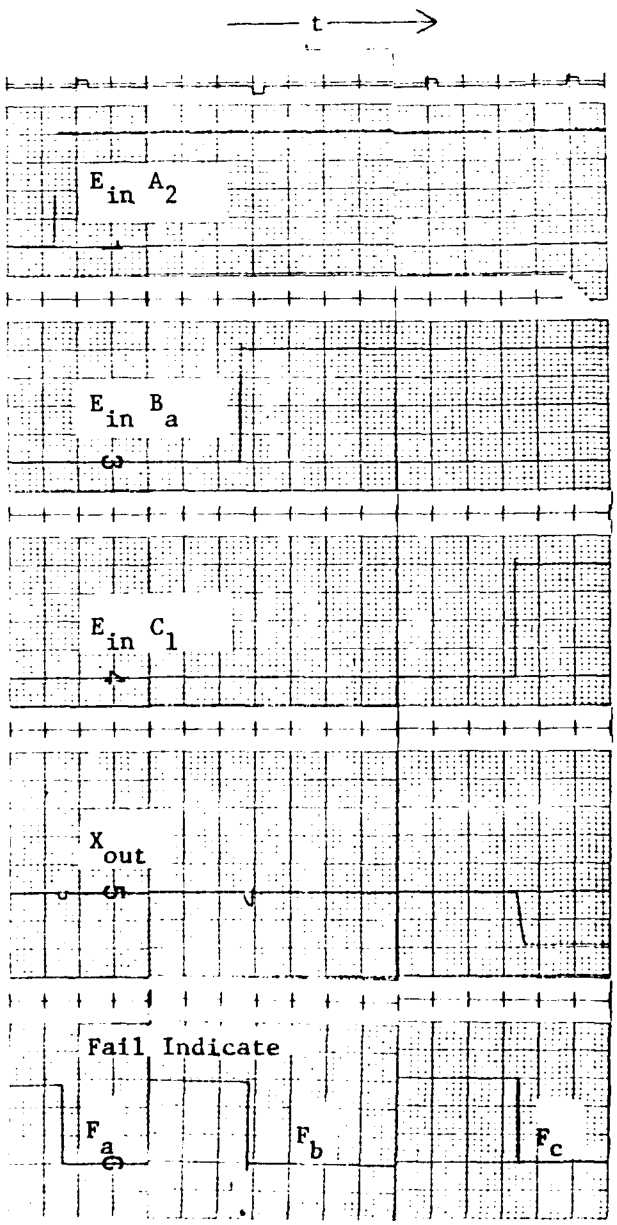
TEST - Failure Transients - Condition 13




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.030 in/div
t = 20 div/sec

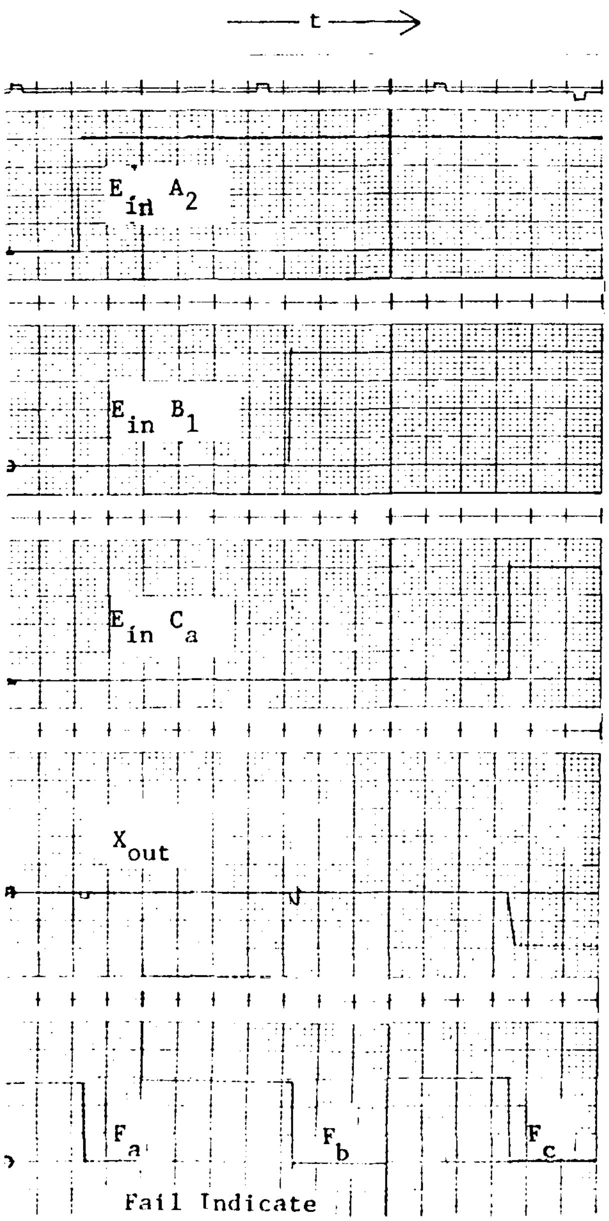
FIGURE 172 Failure Transients - Condition 13

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - National Water Lift Unit

Date Prepared 5/8/79

TEST - Failure Transients - Condition 14




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.030 in/div
t = 20 div/sec

FIGURE 173 Failure Transients - Condition 14

The failure transients shown on Figures 171, 172 and 173 show that the transient amplitude and duration is independent of the operating mode of the particular channel to which the hardover input is applied and is dependent on the redundancy operating mode of the system.

5.5.3.2 Electrical Slowover Input

Figure 174 shows the effect of a slowover extend input applied to the command input of channel A with the other system inputs at null. For this test condition, channels B and C were in the on-line mode of operation. As shown on Figure 174, the system output moves in response to the command channel input up to the point where the input is detected as a failure by the input comparator $K_4$ (Reference Figure 155) and channel A is both depressurized and bypassed and the active mode assigned to channel B. The failure deviation of the actuator output is 2.25% of the maximum actuator stroke. After failure detection, the actuator returns towards a null position at a rate which is on the order of .1% of the actuator stroke per second.

Figure 175 shows the effect of a slowover extend input applied to the command input of channel B with the other system inputs at null. The general configuration of the system is the same as for the failure shown on Figure 174 with channel A the active channel and channel B and C operating in an on-line mode. For the slowover extend input into channel B, the actuator deviates .13% of the total actuator stroke before the input is detected as a failure. This deviation is considerably smaller than that experienced with the slowover input applied to channel A. The smaller deviation is due to the particular mode of operation when the slowover input failure is applied. Since the pressure feedback used to accomplish the on-line mode of operation for a channel prevents the on-line channel from exerting a significant force output (until the pressure

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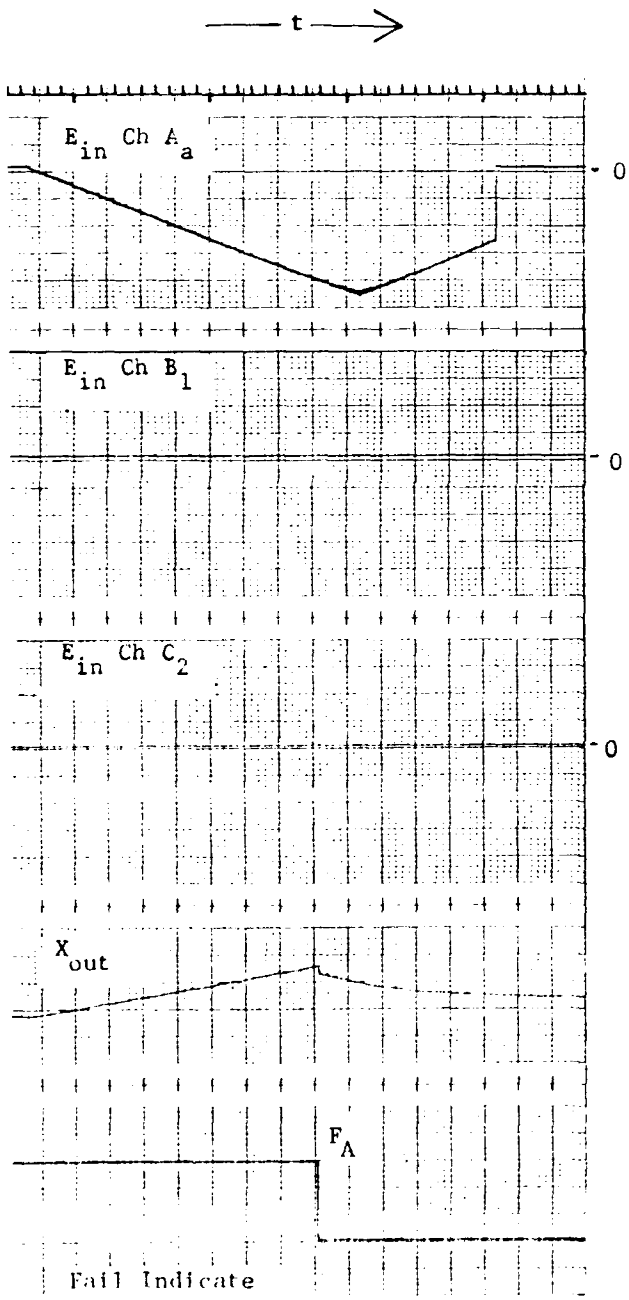
Test Data

TEST ITEM - Grumman - National Water Lift Unit Date Prepared 6/28/79

TEST - Slowover Input Failures - Condition 15 - Ch $A_a$ (Extend)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.003 in/div
t = 2 div/sec

FIGURE 174 Slowover Input Failure - Condition 15 - Ch $A_a$ (Extend)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - National Water Lift Unit

Date Prepared 6/28/79

TEST - Slowover Input Failures - Condition 15 - Ch $B_1$ (Extend)

Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.003 in/div
t = 2 div/sec

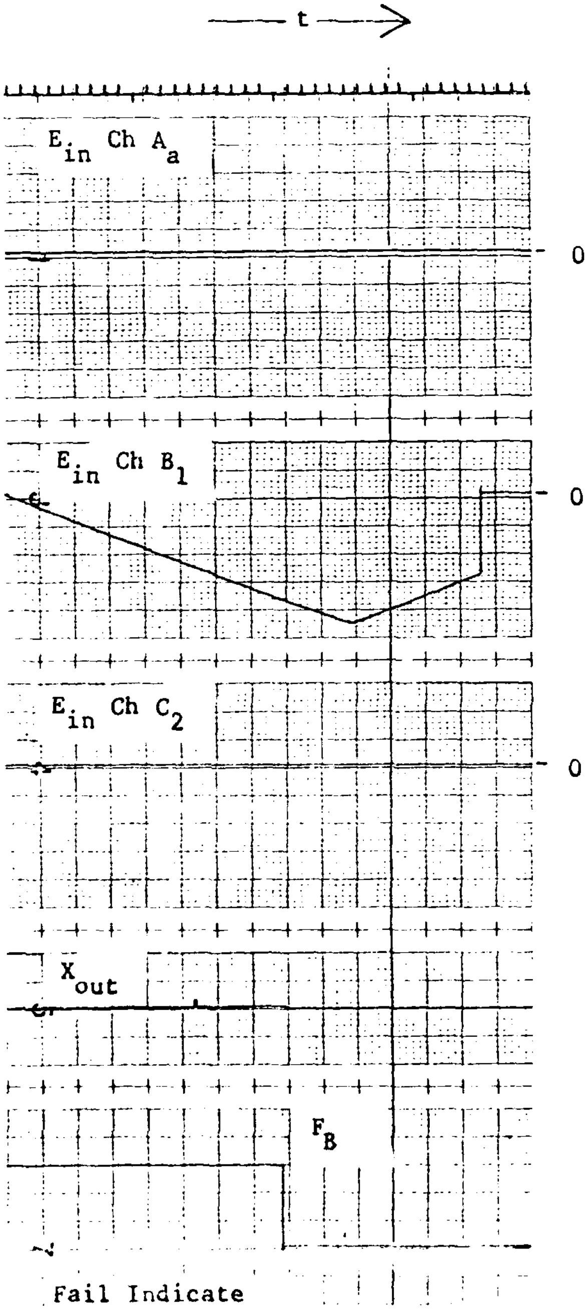



FIGURE 175 Slowover Input Failure - Condition 15 - Ch $B_1$ (Extend)

feedback limit is reached), an on-line channel cannot drive the system output in response to the slowover input.

Figure 176 shows the result of a slowover extend input applied to the command path of channel C with the system configured with channel A the active channel, channel B the first back-up channel (operating in an on-line mode), and channel C the second back-up channel (operating in an on-line mode). The failure deviation is similar to that shown on Figure 175 with a total deviation of the system output of .13% of the total actuator stroke. This deviation is similar to that due to a slowover input into channel B and confirms that an on-line channel subjected to a slowover input signal does not significantly affect the output of the system before the failure is detected and the channel depressurized.

Figures 177, 178 and 179 show the results of applying slowover retract inputs into channels A, B and C respectively with channel A the active channel and channels B and C the on-line channels. The deviation shown on Figure 177 is 2.5% of the maximum actuator stroke. This is slightly greater than that measured for an extend slowover input under the same test condition. The rate of return to a null position after the failure detection is also slightly faster than for the extend position (approximately .2%/second versus .1%/second). The deviation for the slowover applied to channel B (operating in the on-line mode) is .25% (versus .13% for the extend input). The deviation for the slowover input applied to channel C (operating in the on-line mode) is .31% (versus .13% for the extend input and the same operating condition). The difference between the extend and retract slowover deviations is not significant and is probably due to the component tolerances of the channels.

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Test Data

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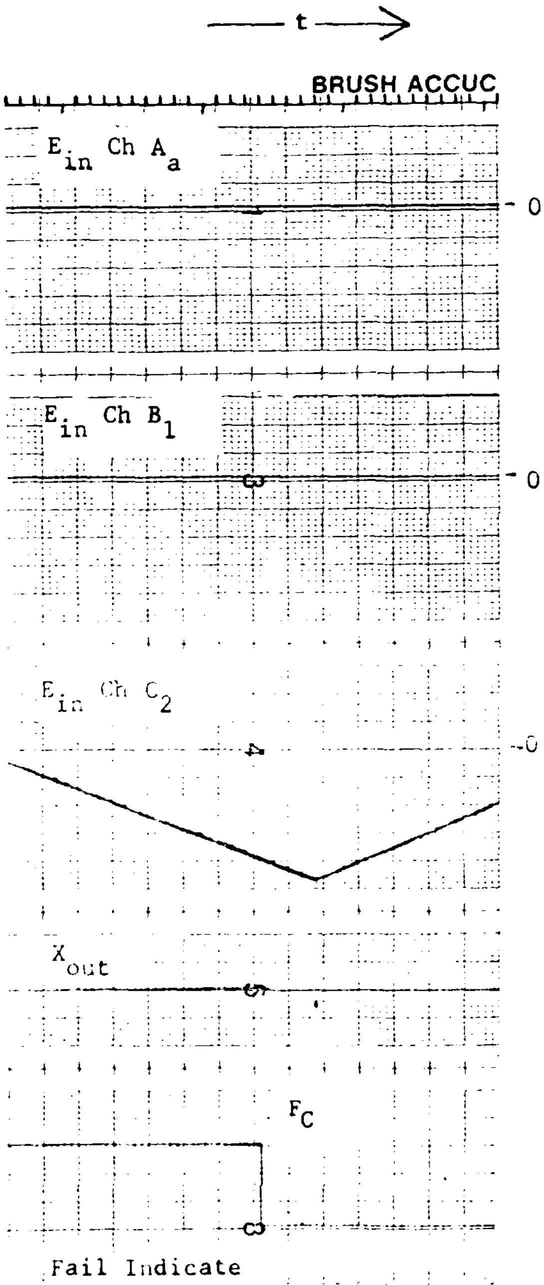
TEST - Slowover Input Failures - Condition 15 - Ch $C_2$ (Extend)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.003 in/div
t = 2 div/sec

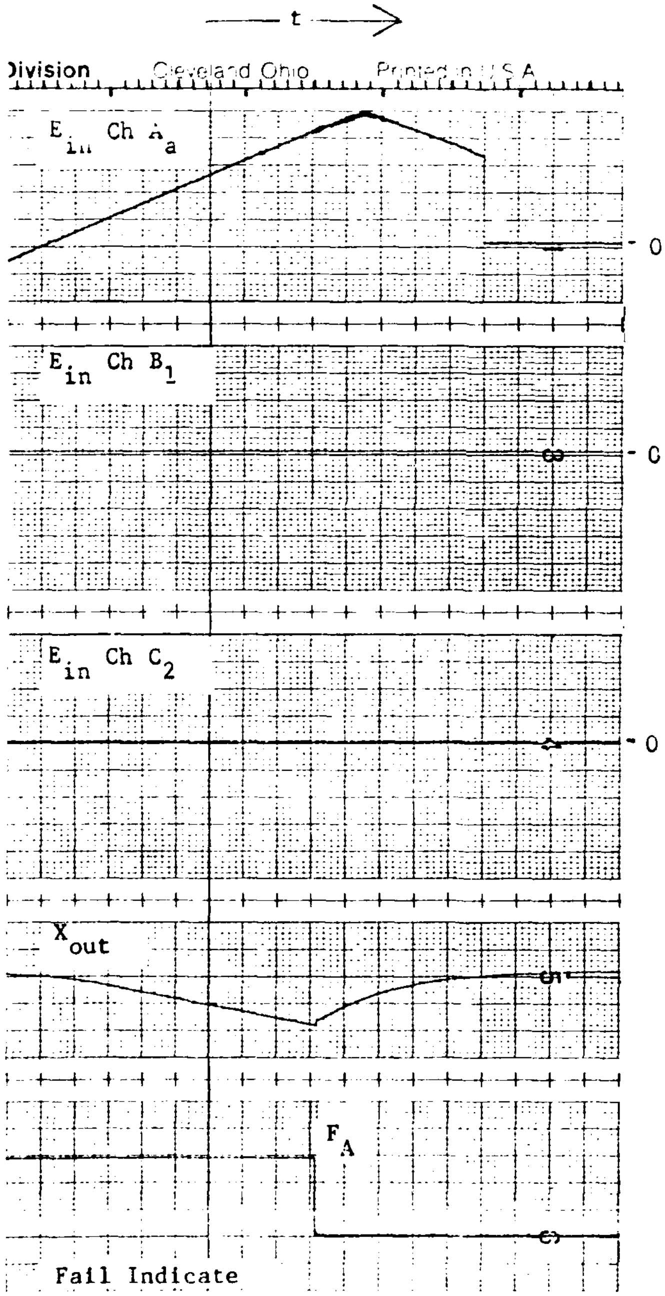
FIGURE 176 Slowover Input Failure - Condition 15 - Ch $C_2$ (Extend)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - National Water Lift Unit

Date Prepared 6/28/79

TEST - Slowover Input Failures - Condition 16 - Ch $A_a$ (Retract)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.003 in/div
t = 2 div/sec

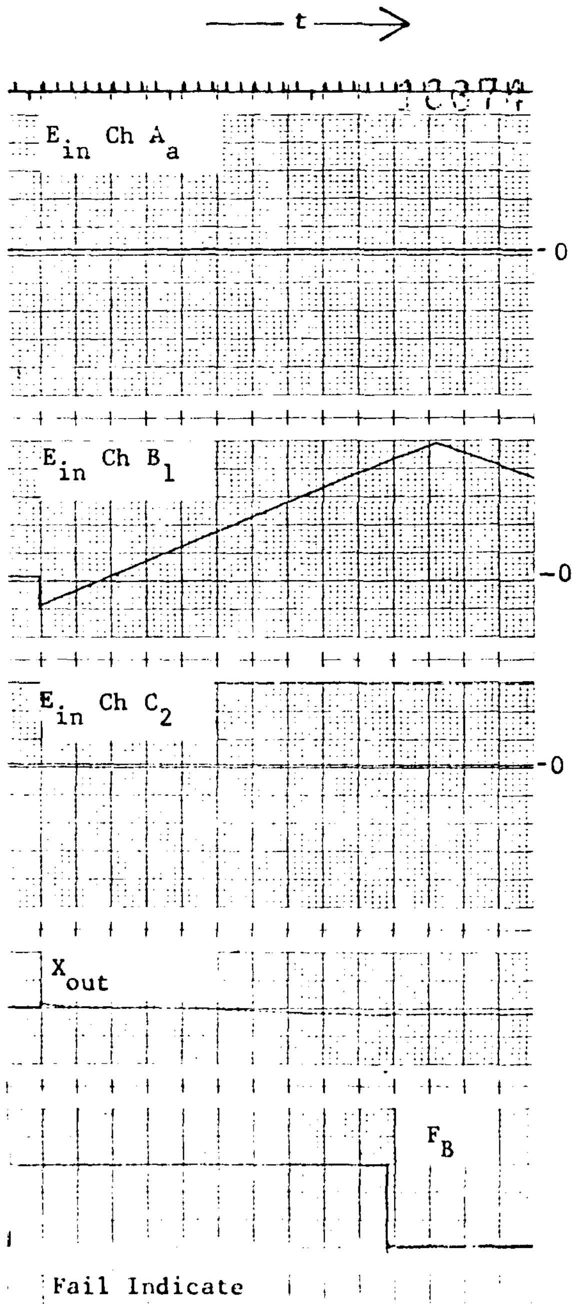
FIGURE 177 Slowover Input Failure - Condition 16 - Ch $A_a$ (Retract)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - National Water Lift Unit

Date Prepared 6/28/79

TEST - Slowover Input Failures - Condition 16 - Ch $B_1$ (Retract)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.003 in/div
t = 2 div/sec

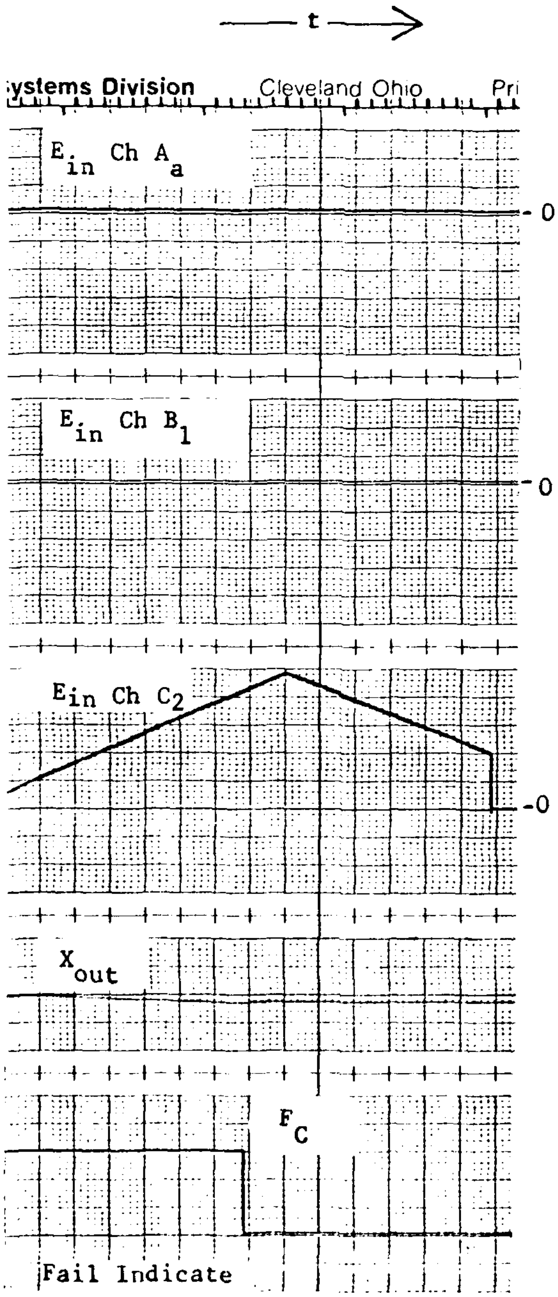
FIGURE 178 Slowover Input Failure - Condition 16 - Ch $B_1$ (Retract)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - National Water Lift Unit

Date Prepared 6/28/79

TEST - Slowover Input Failures - Condition 16 - Ch $C_2$ (Retract)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.003 in/div
t = 2 div/sec

FIGURE 179 Slowover Input Failure - Condition 16 - Ch $C_2$ (Retract)

Figures 180, 181 and 182 show the effect of an extend slowover input applied to channels B, A and C respectively with the other inputs at null. For the test condition of Figures 180, 181 and 182, the system is configured with channel B the active channel and channels A and C the on-line channels. For the slowover input into channel B's command path input, the actuator output deviates 2% of the maximum actuator stroke. After the failure is detected, the system output moves slowly back to a null position. The slowover input into channel A (as shown on Figure 181), produces a system output deviation of .31% of the maximum actuator stroke. The same input applied to channel C produces a system output deviation of .38% of the maximum actuator stroke.

Figures 183, 184 and 185 show the effect of a retract slowover input applied to channels B, A and C command paths respectively with the other inputs at null. The slowover retract input applied to the command path input of channel B (the active channel) produces an output deviation of 2% of the maximum actuator stroke before the failure is detected. The slowover retract input applied to channel A (operating in the on-line mode) produces an output deviation of .25% before the failure is detected. The slowover retract input applied to channel C (operating in the on-line mode) causes an output deviation of .25% before the failure is detected. As with the previous system configuration, the extend and retract slowover input applied to the active channels produce larger output deviations (by a factor of 5 to 10) then the same input applied to the on-line channels.

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Test Data

TEST ITEM - Grumman - National Water Lift Unit

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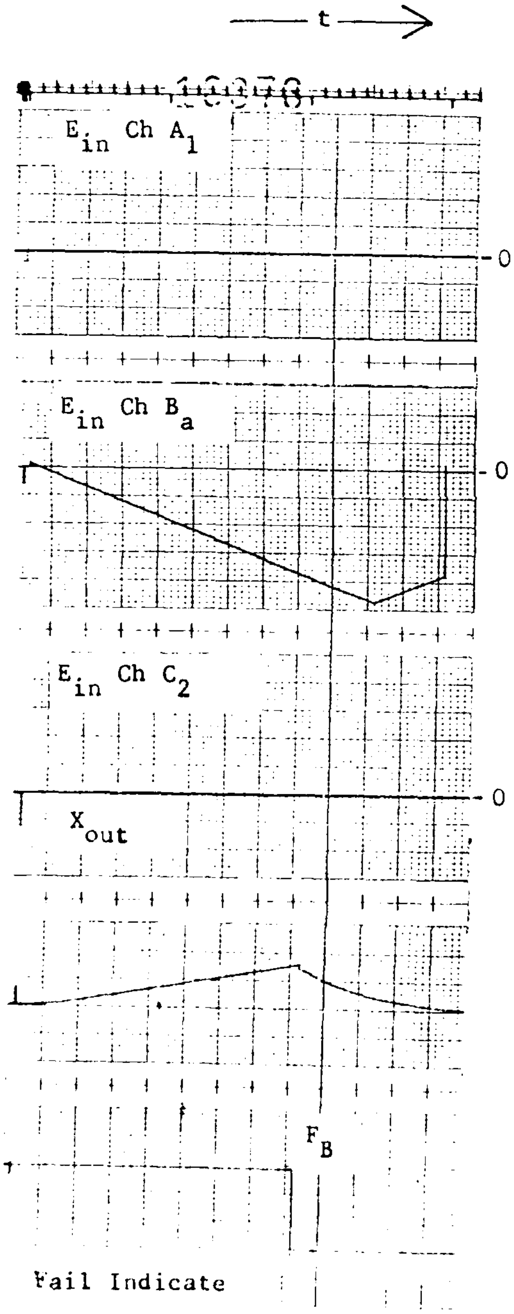
TEST - Slowover Input Failures - Condition 17 - Ch $B_a$ (Extend)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.003 in/div
t = 2 div/sec

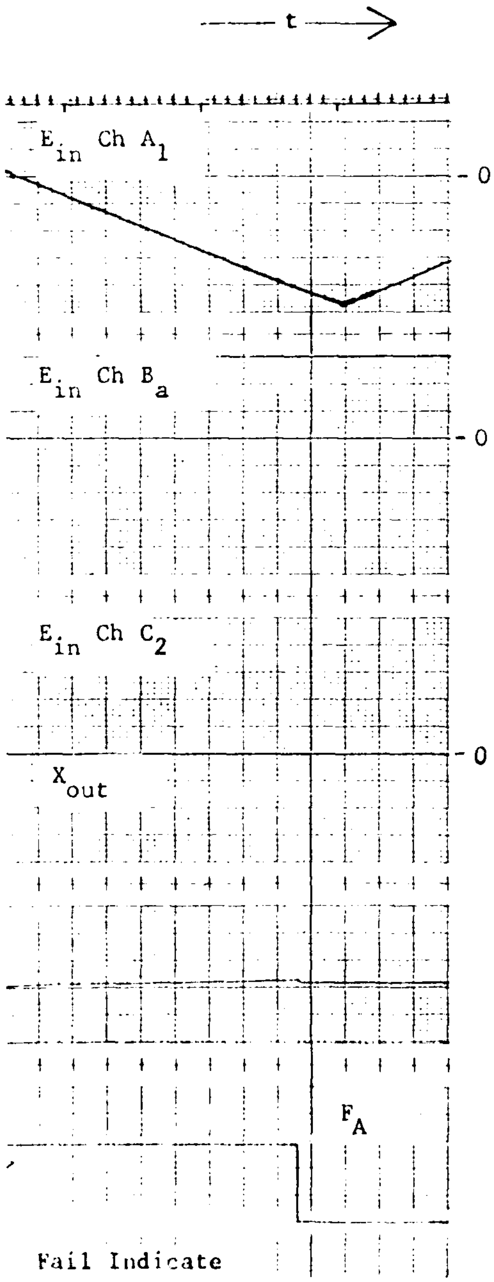
FIGURE 180 Slowover Input Failure - Condition 17 - Ch $B_a$ (Extend)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - National Water Lift Unit

Date Prepared 6/28/79

TEST - Slowover Input Failures - Condition 17 - Ch $A_1$ (Extend)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.003 in/div
t = 2 div/sec

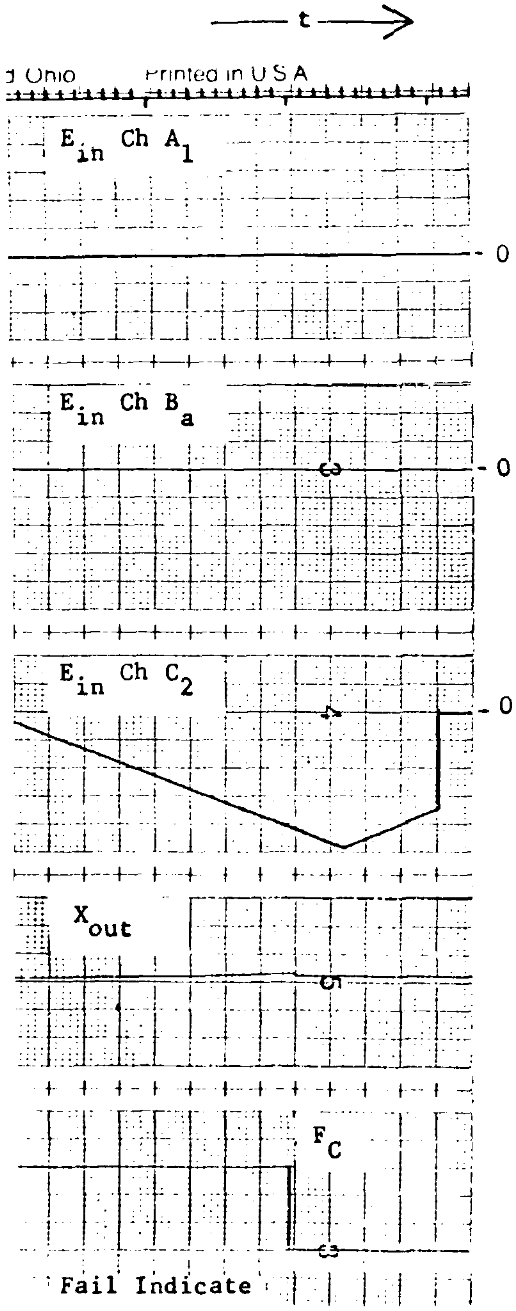
FIGURE 181 Slowover Input Failure - Condition 17 - Ch $A_1$ (Extend)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - National Water Lift Unit

Date Prepared 6/28/79

TEST - Slowover Input Failures - Condition 17 - Ch $C_2$ (Extend)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.003 in/div
t = 2 div/sec

FIGURE 182 Slowover Input Failures - Condition 17 - Ch $C_2$ (Extend)

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Test Data

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TEST - Slowover Input Failures - Condition 18 - Ch $B_a$ (Retract)

Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.003 in/div
t = 2 div/sec

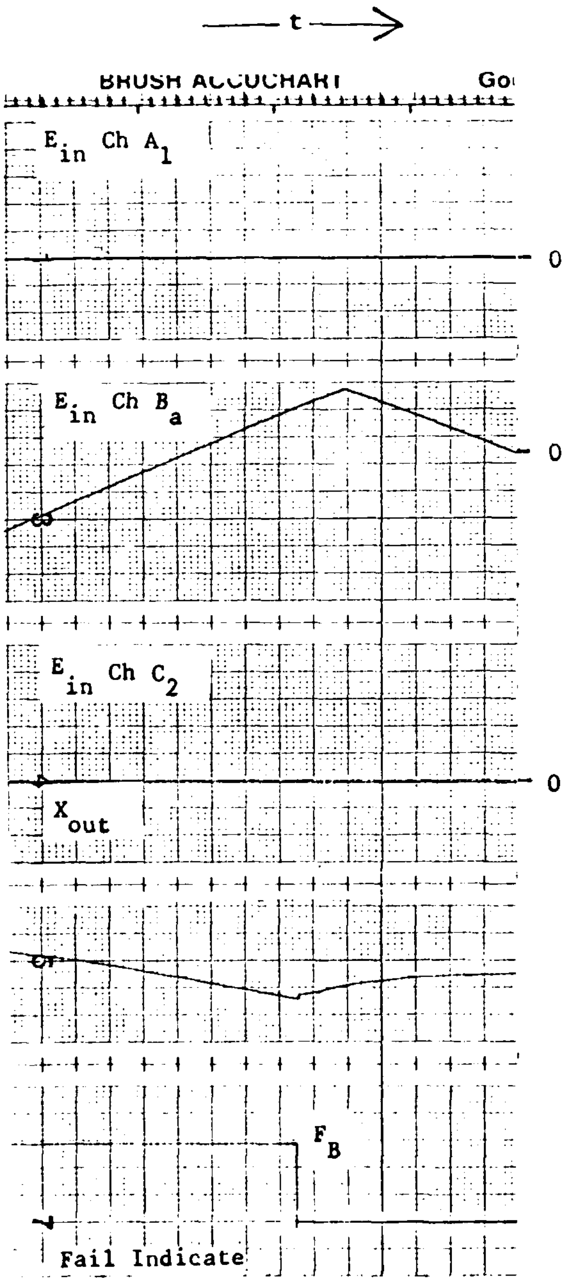


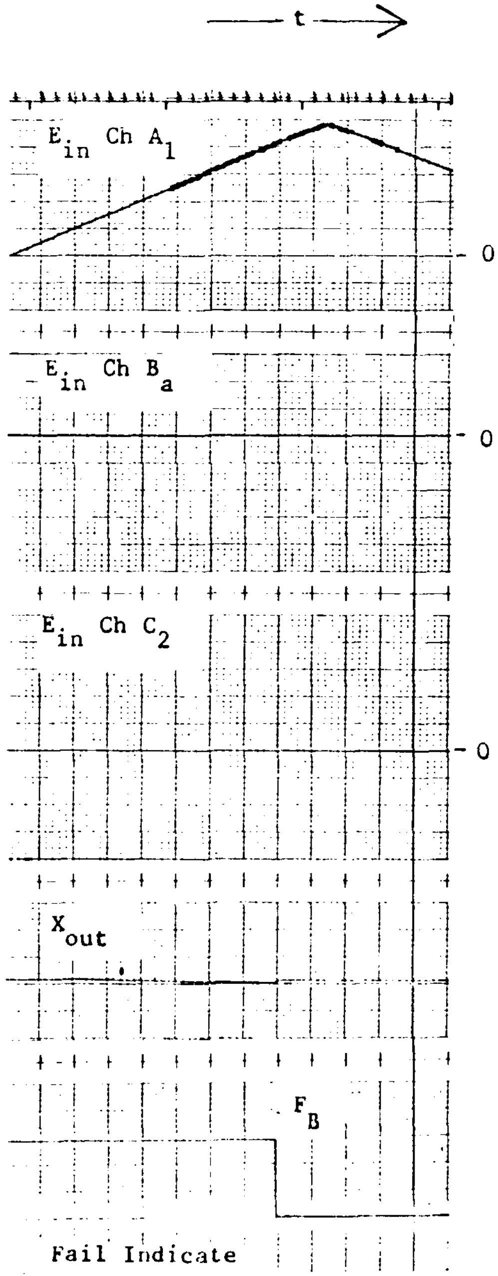

FIGURE 183 Slowover Input Failure - Condition 18 - Ch $B_a$ (Retract)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - National Water Lift Unit

Date Prepared 6/28/79

TEST - Slowover Input Failures - Condition 18 - Ch $A_1$ (Retract)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.003 in/div
t = 2 div/sec

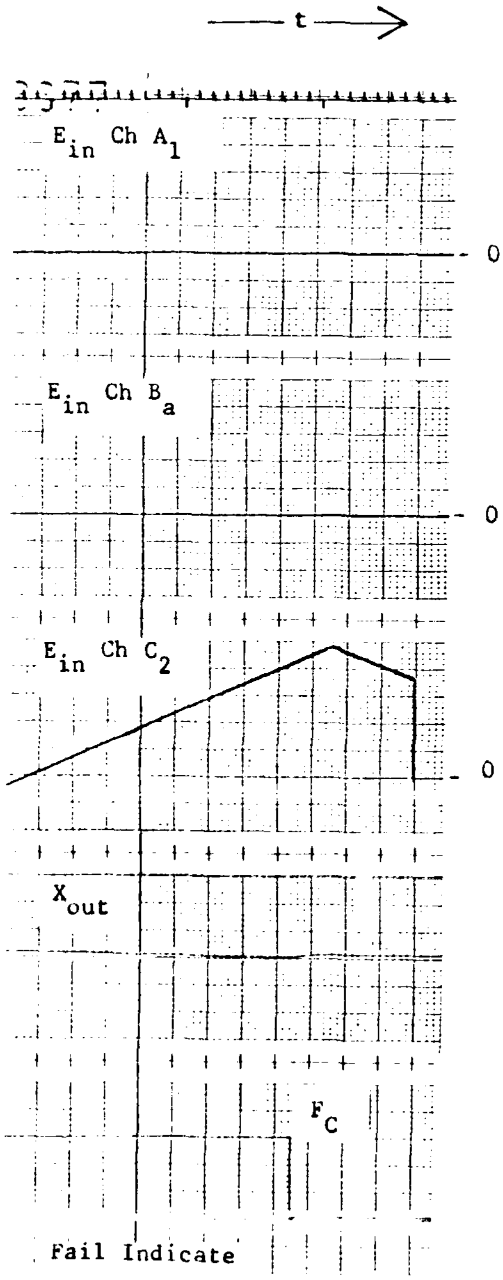
FIGURE 184 Slowover Input Failures - Condition 18 - Ch $A_1$ (Retract)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - National Water Lift Unit

Date Prepared 6/28/79

TEST - Slowover Input Failures - Condition 18 - Ch $C_2$ (Retract)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.003 in/div
t = 2 div/sec

FIGURE 185 Slowover Input Failure - Condition 18 - Ch $C_2$ (Retract)

Figures 186, 187 and 188 show the effect of an extend slowover input applied to channels C, B and A respectively with the other inputs at null. For these particular figures, the system is configured with channel C as the active channel and channels B and A operating in the on-line mode. For the slowover input into channel C's command input as shown on Figure 186, the actuator output moves 2% of the maximum actuator stroke before the failure input is detected and channel C depressurized and bypassed. After the failure is detected and the active channel mode transferred to channel B, the actuator output returns towards null the rate of return requiring approximately 14 seconds to reach the null position. The slowover input applied to the command path of the channel B operating in the on-line mode causes the actuator output to deviate .13% of the maximum actuator stroke before the failure is detected. The slowover extend input into the command path of channel A operating in an on-line mode causes the actuator to deviate .13% of the maximum actuator stroke before the failure is detected.

Figures 189, 190 and 191 show the effect of a retract slowover input applied to channels C, B and A respectively with the other inputs at null. For these figures (as for Figures 186, 187 and 188) the system is configured with channel C operating in the active mode and channels B and A operating in the on-line mode. The deviation for the slowover retract input applied to the command path of channel C is shown on Figure 189 and is 1.75% of the maximum actuator stroke. The actuator returns towards null after the failure input is detected, taking approximately 10 seconds to reach the null position. Figure 190 shows the same input applied to the command path input for channel B operating in the on-line mode. The actuator output deviation is .13% of the total actuator stroke. Figure 191 shows the retract slowover input applied to the command path of channel A operating in the on-line mode. The actuator output deviation is .25% of the maximum actuator stroke.

DYNAMIC CONTROLS, INC.
Test Data

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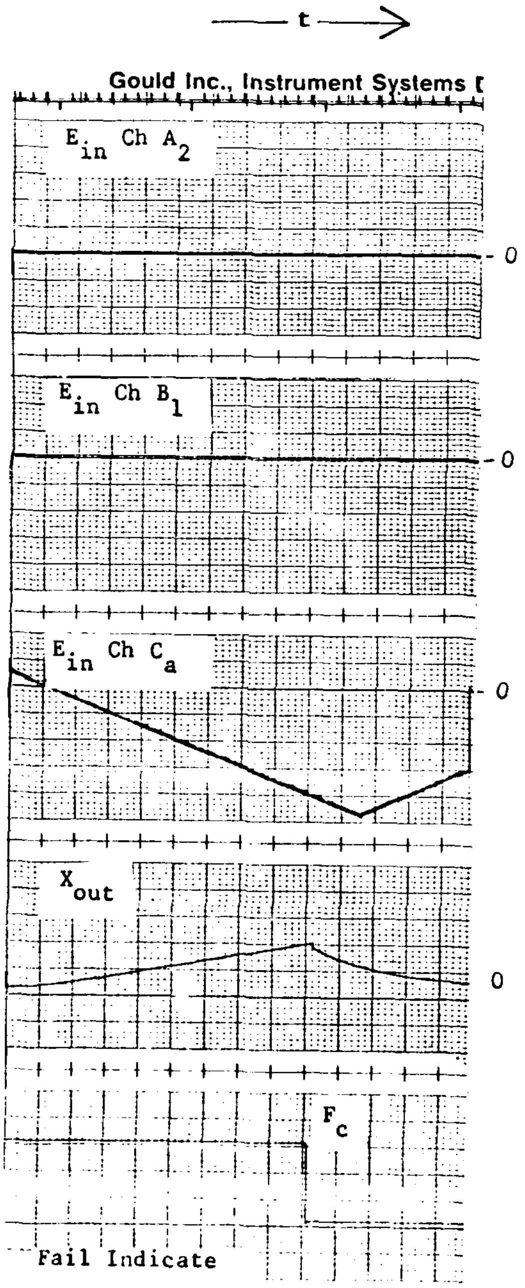
TEST - Slowover Input Failures - Condition 19 - Ch $C_a$ (Extend)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.003 in/div
t = 2 div/sec

FIGURE 186 Slowover Input Failures - Condition 19 - Ch $C_a$ (Extend)

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Test Data

TEST ITEM - Grumman - National Water Lift Unit

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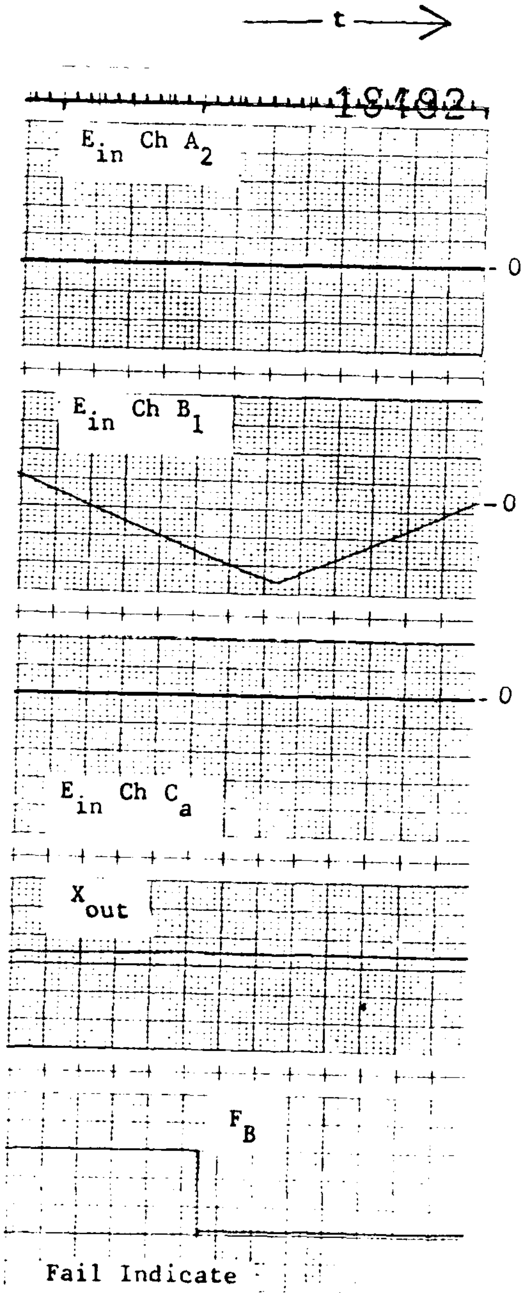
TEST - Slowover Input Failures - Condition 19 - Ch $B_1$ (Extend)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.003 in/div
t = 2 div/sec

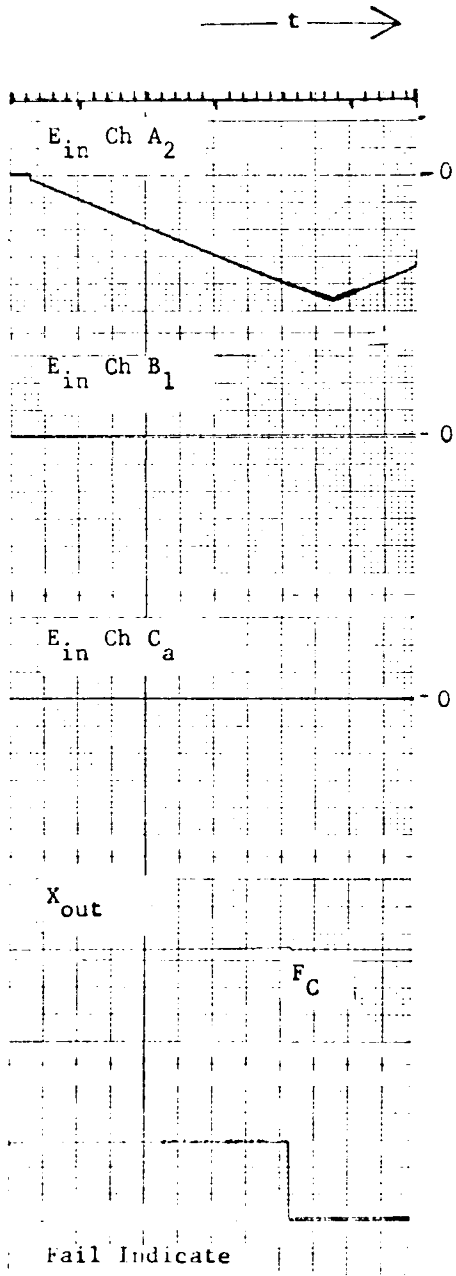
FIGURE 187 Slowover Input Failures Condition 19 - Ch $B_1$ (Extend)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - National Water Lift Unit

Date Prepared 6/28/79

TEST - Slowover Input Failures - Condition 19 - Ch $A_2$ (Extend)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.003 in/div
t = 2 div/sec

FIGURE 188 Slowover Input Failures - Condition 19 - Ch $A_2$ (Extend)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - National Water Lift Unit

Date Prepared 6/28/79

TEST - Slowover Input Failures - Condition 20 - Ch $C_a$ (Retract)

Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.003 in/div
t = 2 div/sec

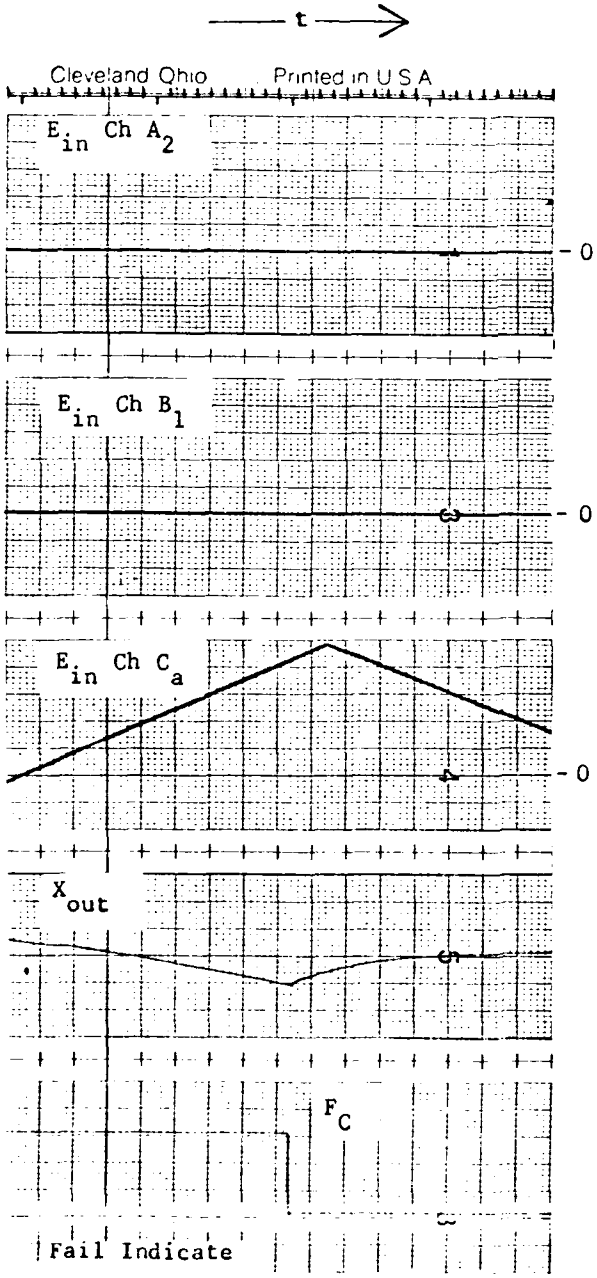



FIGURE 189 Slowover Input Failures - Condition 20 - Ch $C_a$ (Retract)

DYNAMIC CONTROLS, INC.
Test Data

TEST ITEM - Grumman - National Water Lift Unit

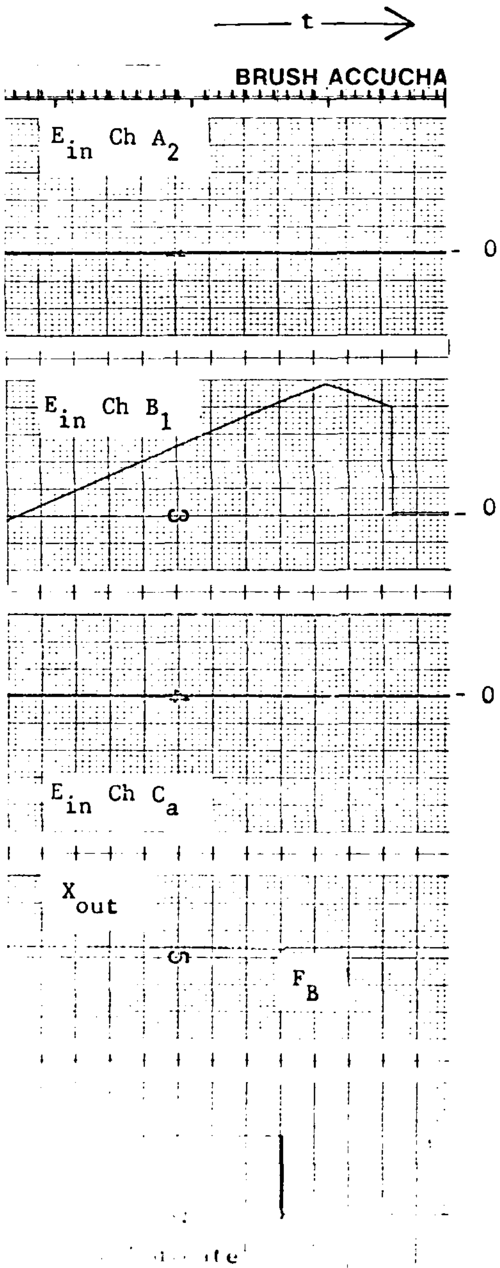
Date Prepared 6/28/79

TEST - Slowover Input Failures - Condition 20 - Ch $B_1$ (Retract)

Scale: $E_{in}$ = 0.050 v/div

$X_{out}$ = 0.003 in/div

t = 2 div/sec




Slowover Input Failures - Condition 20 - Ch $B_1$ (Retract)

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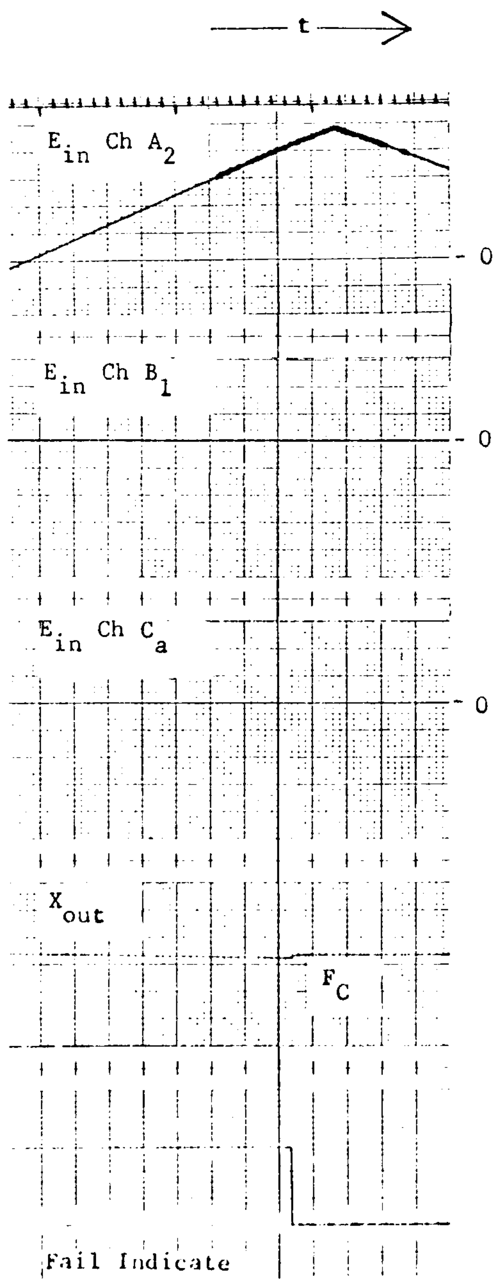
Test Data

TEST ITEM - Grumman - National Water Lift Unit

Date Prepared 6/28/79

TEST - Slowover Input Failures - Condition 20 - Ch $A_2$ (Retract)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.003 in/div
t = 2 div/sec

FIGURE 191 Slowover Input Failures - Condition 20 - Ch $A_2$ (Retract)

The preceding Figures 176 through 191 show the effect of both extend and retract slowover input failures with the active/on-line system configured in three different ways. These configurations vary the active channel assignment between channels A, B and C (with the remaining channels for each active channel assignment being assigned the on-line mode of operation).

The effect of the slowover input failures for all of these test conditions is quite similar. The slowover input failures into the command path of the active channels produces actuator output deviations of nominally 2% of the maximum actuator stroke. The same input into a channel operating in the on-line mode produces actuator output deviations of nominally .2%.

The amplitude of the actuator deviations caused by the slowover input failure to an active channel is from two to three times greater than that measured on the Bertea Force Sharing System configurations. The slowover input into the on-line channels causes less actuator output deviations (by approximately one half) than that measured on the Bertea Force Sharing System for slowover input failures.

In general, the actuator output deviation of a redundant system with slowover input failures is directly determined by the failure detection level for the configuration and the degree of force fight limiting the output motion. The detection level for the active/on-line system was set at 10% of the input for total actuator stroke. The Bertea Force Sharing System detection level was set at 4% of the maximum input voltage for maximum actuator output stroke. From just the failure detection level, the deviation resulting from a slowover input failure would be expected to be lower with the Bertea system than with the active/on-line system. In addition, because the force sharing system provides a "motion restricting" force fight for failures of a single channel (and the active/on-line does not until the pressure feedback of the on-line channels saturates), the deviation with the force sharing system would be expected to be lower. The expected results were confirmed by the slowover input test results.

### 5.5.3.3 Open Servovalve Coil Failure Transients

The failure transient resulting from inner loop failures of the active/on-line configuration was evaluated as part of the test program. This type of failure depends on an inner loop failure detection logic in order for failure detection and corrective action to be taken. Servovalve and pressure feedback loop failures of the active/on-line system are detected by comparator $K_1$ (Reference Figure 155). The normal hardover and slowover input failures used for the preceding input failures exercise comparator $K_4$ rather than $K_1$. Since the mechanization averages the model and command path control errors immediately after $K_4$, the $K_1$ comparator is required to detect servovalve and pressure feedback loop failures. Open coil servovalve failures are a passive type failure and are not detected until the system is subjected to a dynamic input, since the servovalve has no input when the system output is not moving. Therefore, the effect of an open servovalve coil was evaluated with the system cycling at 1 Hz at an input command (and output displacement) of 10% of the maximum actuator output displacement.

Figure 192 shows the effect of a servovalve coil failure first in channel A and then channels B and C (with the system configured with channel A active, channel B the first backup channel and channel C the second backup channel). The top chart strip of Figure 192 shows the command input applied to channels A, B and C. The second chart strip from the top shows the actuator output motion. The bottom three chart strips show the failure indicate voltages of the system, corresponding to detected failures of channels A, B and C. As shown on Figure 192, for the first failure into the active channel the output deviation is 1% of the maximum actuator stroke, with the deviation lasting a total of .15 seconds. The second coil failure (channel B) produces an amplitude deviation of 3.5% of the maximum actuator stroke. The third failure (channel C) is detected and the channel depressurized.

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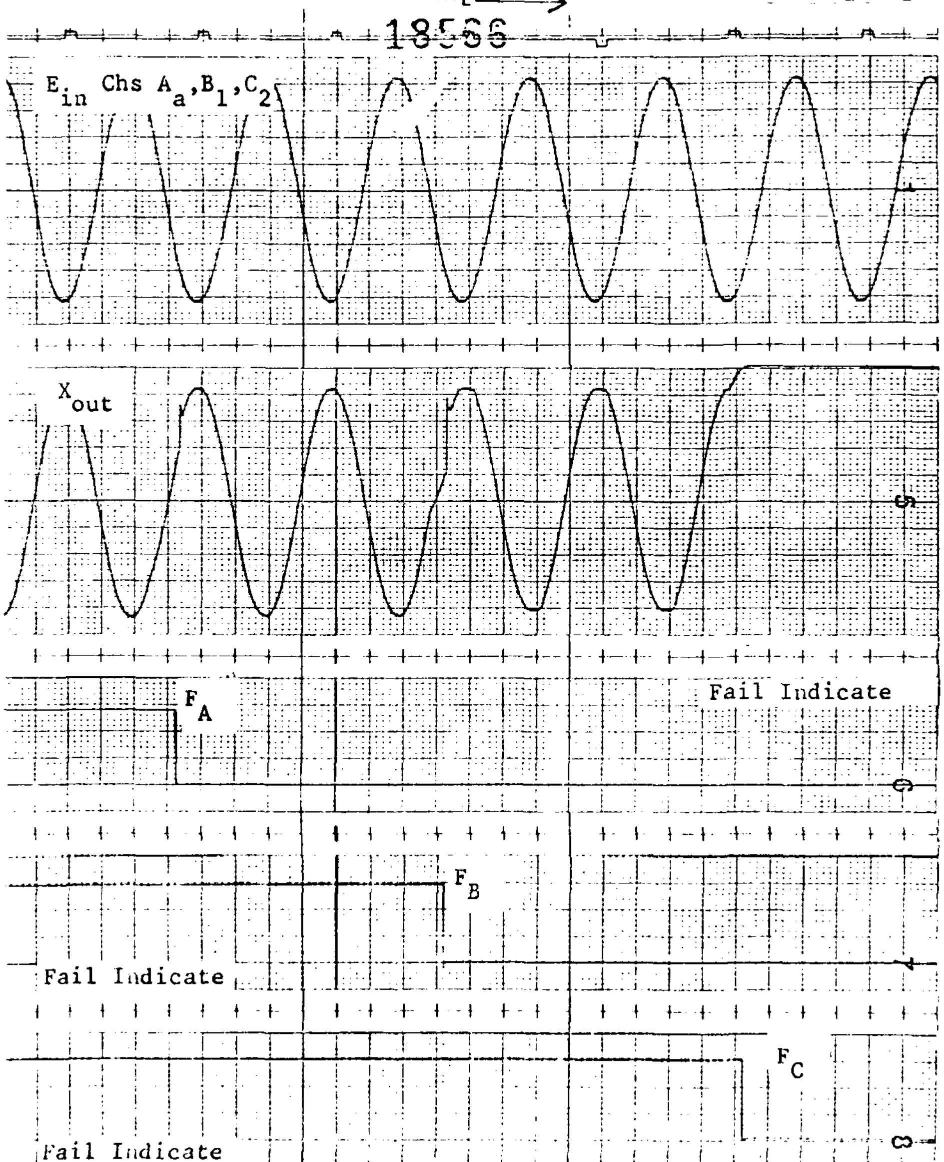
Date Prepared 6/28/79

Test - Servovalve Coil Failures - Condition 21 - Chs $A_a$, $B_1$, $C_2$




Scale: $E_{in}$ = 0.100 v/div
$X_{out}$ = 0.006 in/div
t = 20 div/sec

FIGURE 192 Servovalve Coil Failures - Condition 21
Chs $A_a$, $B_1$, $C_2$

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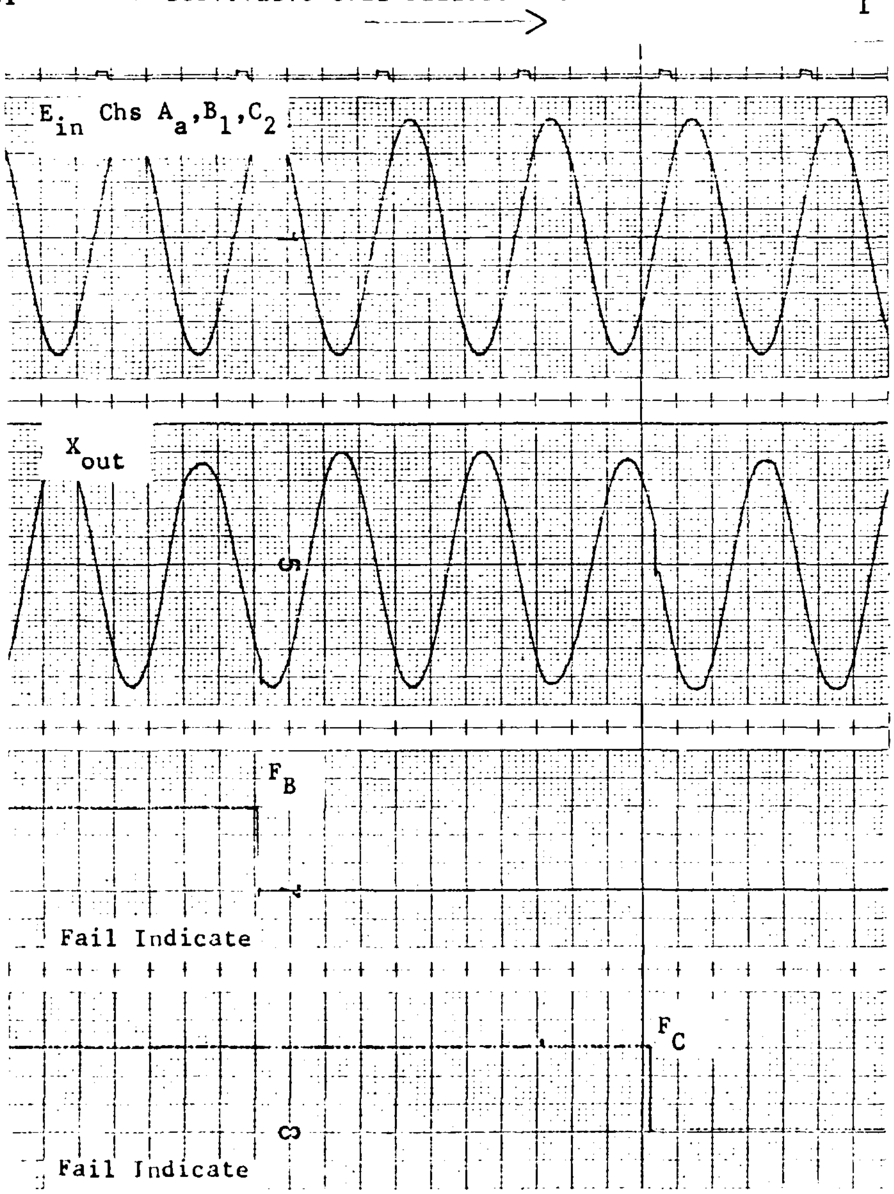
TEST ITEM - Grumman - National Water Lift Unit

Date Prepared 6/29/79

TEST - Servovalve Coil Failure - Condition 22 - Chs $B_1$ & $C_2$




Scale: $E_{in}$ = 0.100 v/div

$X_{out}$ = 0.006 in/div

t = 20 div/sec

FIGURE 193 Servovalve Coil Failure - Condition 22 - Chs $B_1$ & $C_2$

Note that the servovalve coil failure effects shown on Figure 192 are with the channels being failed operating in the active mode. After the failure of the channel A coil, the active channel is transferred to channel B. Channel C's servovalve coil for the third failure occurs after a failure of channel B makes channel C an active channel.

Figure 193 shows the effect of open coil failures occurring in on-line channels (as opposed to Figure 192's open coil failures in the active channels). For the configuration operating with channel A the active channel and channel B and C the on-line channels, the first open coil failure in on-line channel B creates an output deviation of 1.5%. The second failure creates an output deviation of 3.0% of the maximum actuator stroke. The relatively large transients (compared to those encountered with the slowover failures) of the on-line channel failures is due to the response characteristic of the pressure feedback loop. The pressure feedback loop operates only at very low frequencies. At the 1 Hz input frequency used for Figures 192 and 193, the pressure feedback is ineffective and the mechanization and the configuration is operating as a force sharing system. Therefore, the failures within the on-line channels at frequencies above the break frequency of the pressure feedback loop (.03 Hz) have the same effect on the system output as failures of the active channel.

Figure 194 shows the effect of an open servovalve coil on the system output with the input to the control system at null. For this test the control system was configured with channel A as the active channel and channels B and C the on-line channels. The first open coil failure is applied to channel B. This causes a gradual output change (the channel B servovalve is not electrically controlled and the null unbalance output flow from the servovalve causes the system

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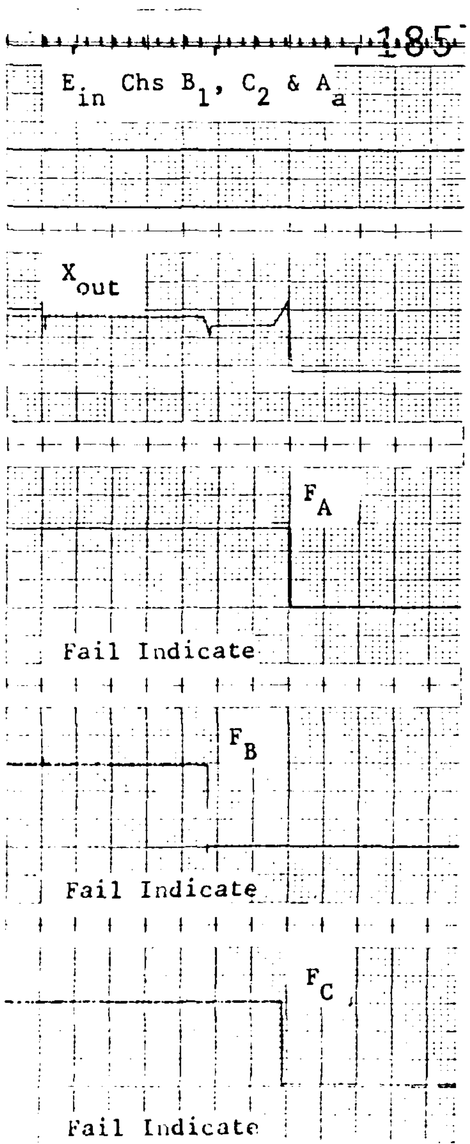
TEST - Servovalve Coil Failures - Condition 23 - Chs $B_1$, $C_2$ & $A_a$




Scale: $E_{in}$ = 0.100 v/div
$X_{out}$ = 0.006 in/div
t = 2 div/sec

FIGURE 194 Servovalve Coil Failures - Condition 23 - Chs $B_1$, $C_2$ & $A_a$

output to drift). The failure is not detected until the actuator feedback drives the channel B servovalve model to a failure detection level by comparator $K_1$ (reference Figure 155). The output deviation resulting from the channel B failure is 1.5% of the actuator maximum stroke. After the failure detection, the actuator returns towards the original null position and stops at a null offset of .75% of the actuator stroke. The second open feedback coil failure causes an output deviation of 2% of the maximum actuator stroke. As shown on Figure 194, the third open feedback coil failure occurs in channel A immediately after the second servovalve open failure and causes the failure logic to disable channel C.

5.5.3.4 Open Actuator Feedback Failure Transient

Figure 195 shows the effect of an open actuator feedback signal in the model path of an active channel. The demonstrator as mechanized used a switch in the model path feedback only, precluding the option of failing the command path actuator feedback signal. Since the command path feedback for no input command to the system would prevent the actuator output from drifting and the model path feedback failure from being detected, the effect of the failure was evaluated with a dynamic input to the system. The input used was a 1 Hz sinusoidal input at an amplitude of 10% of the maximum command input. As shown on Figure 195, the open actuator feedback failure of channel A causes an output deviation of 3.5% of the maximum actuator stroke. The second feedback failure into channel B causes an output deviation of 4.5% of the maximum actuator stroke. The time duration of the transient for both channel failures is .05 seconds. The third feedback failure into channel C is correctly detected and the channel depressurized.

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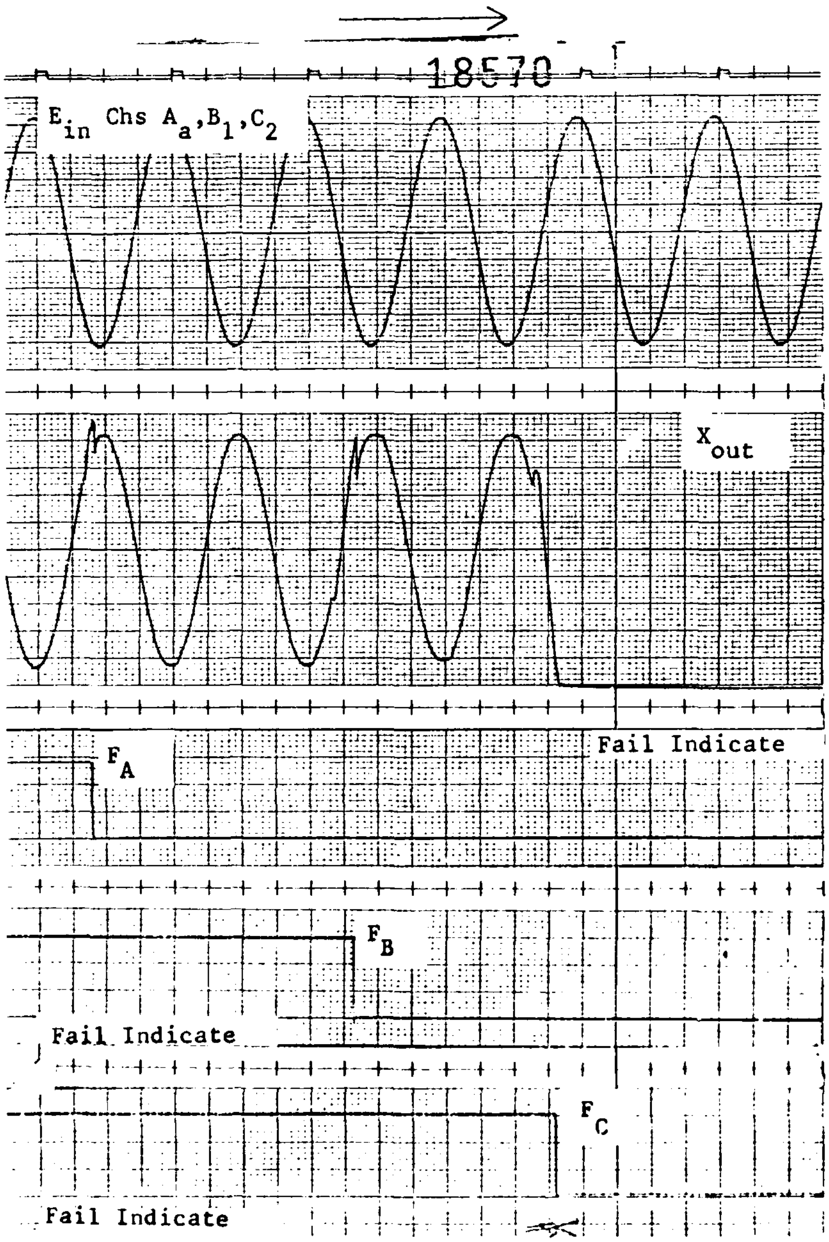
TEST ITEM - Grumman - National Water Lift Unit

Date Prepared 6/28/79

TEST - Actuator Position Feedback Failure
Condition 24 - Chs $A_a$, $B_1$, $C_2$




Scale:
$E_{in}$ = 0.100 v/div
$X_{out}$ = 0.006 in/div
t = 20 div/sec

FIGURE 195 Actuator Position Feedback Failure
Condition 24 - Chs $A_a$, $B_1$,$C_2$

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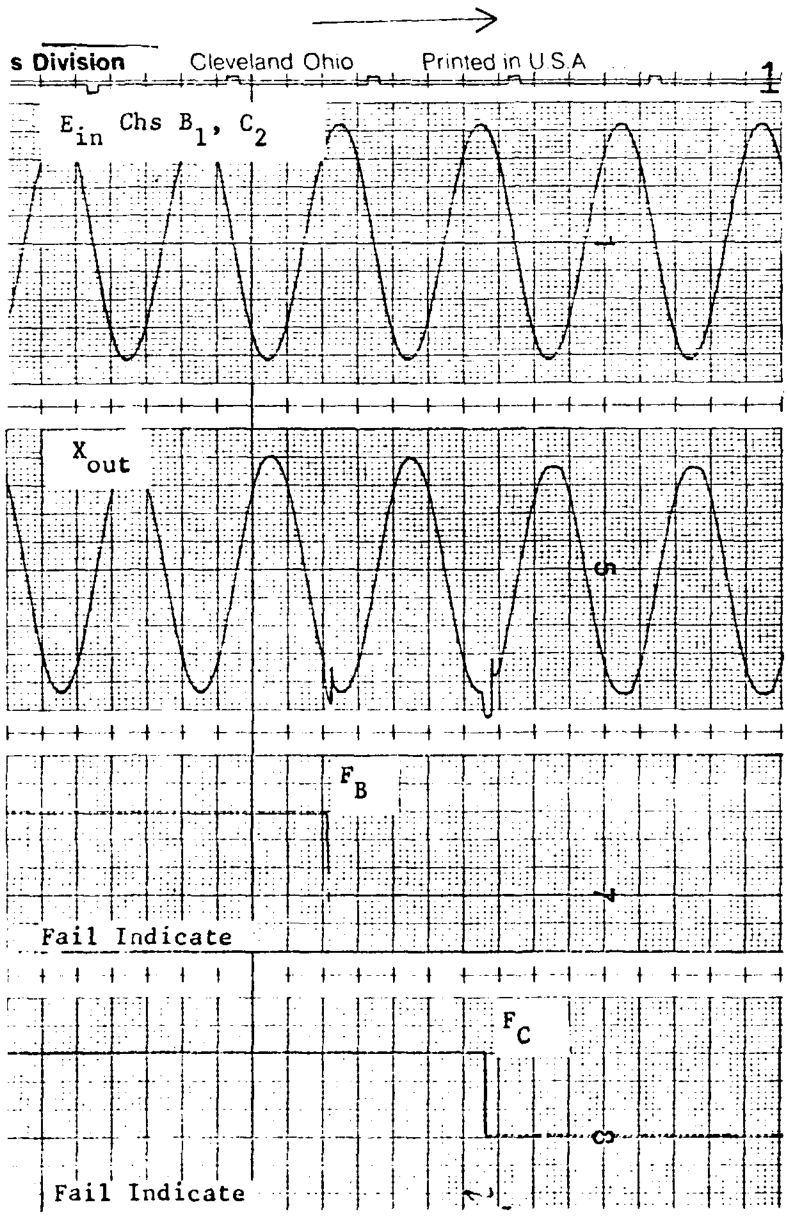
Test Data

TEST ITEM - Grumman - National Water Lift Unit

Date Prepared 6/28/79

TEST - Actuator Position Feedback Failure Condition 25 - Chs $B_1$ $C_2$




Scale:
$E_{in}$ = 0.100 v/div
$X_{out}$ = 0.0006 in/sec
t = 20 div/sec

FIGURE 196 Actuator Position Feedback Failure Condition 25 - Chs $B_1$ $C_2$

Figure 196 shows the effect of an open feedback failure of the model path to an on-line channel. Since the actuator is operating at 1 Hz, the on-line channels contributed to the force output of the system. Therefore, the on-line channel open feedback failure effects are similar to that of the active channel feedback failures. For the first open feedback failure of channel B, the deviation of the system output is 2% of the maximum actuator stroke. The second failure of channel C also causes a deviation of 2% of the maximum actuator stroke. The duration of the deviations is from .05 to .075 seconds.

This test demonstrates that the failure logic detects correctly the feedback failures under dynamic conditions and transfers the active channel control to the correct channel with a reasonably short duration and low amplitude transient. Since the feedback failures are of the model paths, rather than the control paths, the output transients observed are due to the failure logic transferring out the failed channels. The transient might be different if the failures were in the command paths of the control channel.

### 5.5.3.5 Simultaneous Input Failure Effects

Figure 197 shows the effect of simultaneous loss of both the command path and model path input signals in one channel of the active/on-line system. As shown on Figure 197, the system is configured with channel A the active channel, channel B and C the on-line channels. On Figure 197, the top three data strips show the inputs to the three channels. Initially all three channels are driven with the same 10 Hz input at an amplitude corresponding to 10% of the input for the maximum actuator position. This is the maximum input level which can be used without rate saturation over the entire system bandpass. At the 10 Hz input frequency, all channels are contributing to the driving force of the system output, since the pressure feedback signals for the

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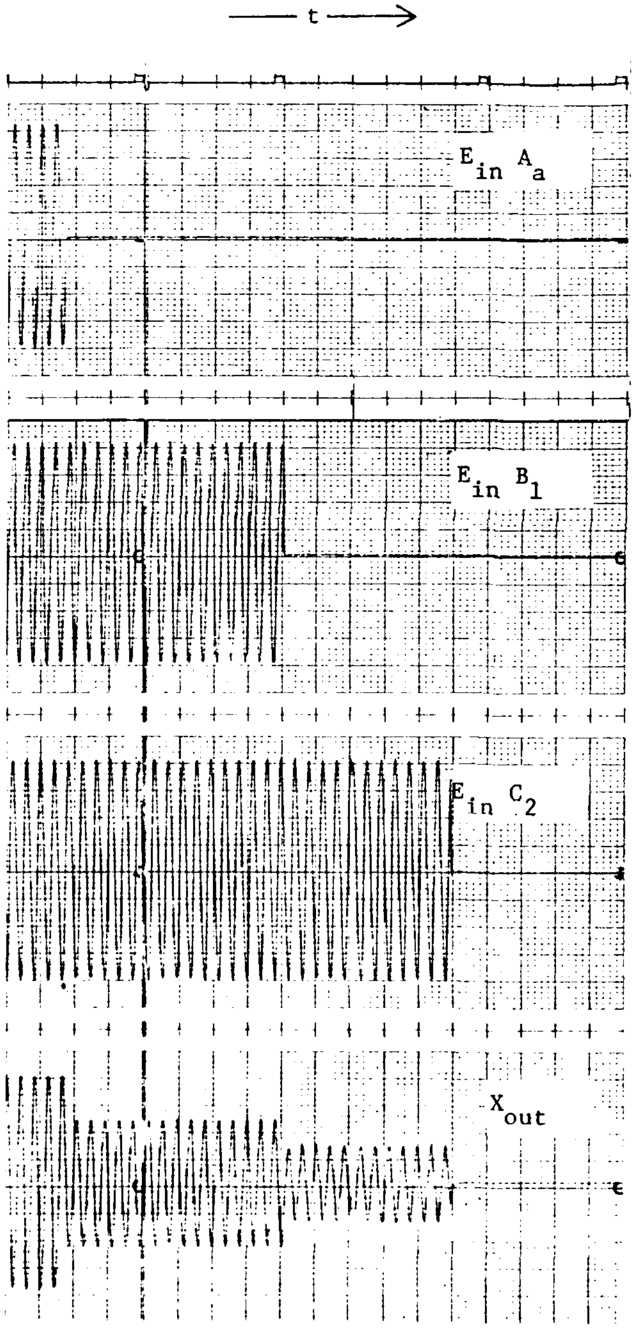
Test Data

TEST ITEM - Grumman - National Water Lift Unit

Date Prepared 5/8/79

TEST - Failure Transients - Condition 26




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.003 in/div
t = 20 div/sec

FIGURE 197 Failure Transients - Condition 26

on-line channels are effective only below 1 Hz. The loss of the input to channel A is not detected as a channel failure, since the failure creates an identical input for both the model and command path of the channel. The loss of channel A's input creates a force fight between channel A and channels B and C. The net effect is a reduction in output amplitude to 57% of that measured with no failed input. For the second failure of the input to channel B, the amplitude is reduced to 32% of the amplitude with no input failures. For this second failure, channel A and B are being commanded to a null output position and channel C is commanded to respond to the 10 Hz input, resulting in a force fight between the three channels. For the third input loss, all three channels are being commanded to a null position and the output of the system responds to that null command. These results are that of a three channel force sharing system without any failure detection and switching. The output change is that of a simple force vote between the channels with a null input and a 10 Hz input.

Figure 198 shows the effect of positive hardover input signals applied to both the command and model path inputs of channels A, B and C. Since the hardover inputs are applied to both the command and model path inputs at the same time, the failure logic for each channel does not detect the failure. The effect of the hardover input into channel A (as shown on Figure 198) is a small initial offset of the actuator output and then a gradual displacement away from the original position until a steady displacement away from the original position stroke is approached. The limited initial deflection upon the application of the hardover input into the active channel A is due to the action of the negative pressure feedback loop on the on-line channels not being effective for dynamic inputs. The on-line channels oppose the active channel dynamically. The gradual drift of the system output after

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JUL 80 G D JENNEY F33615-77-C-3077
UNCLASSIFIED AFFDL-TR-79-3117-VOL-2 NL

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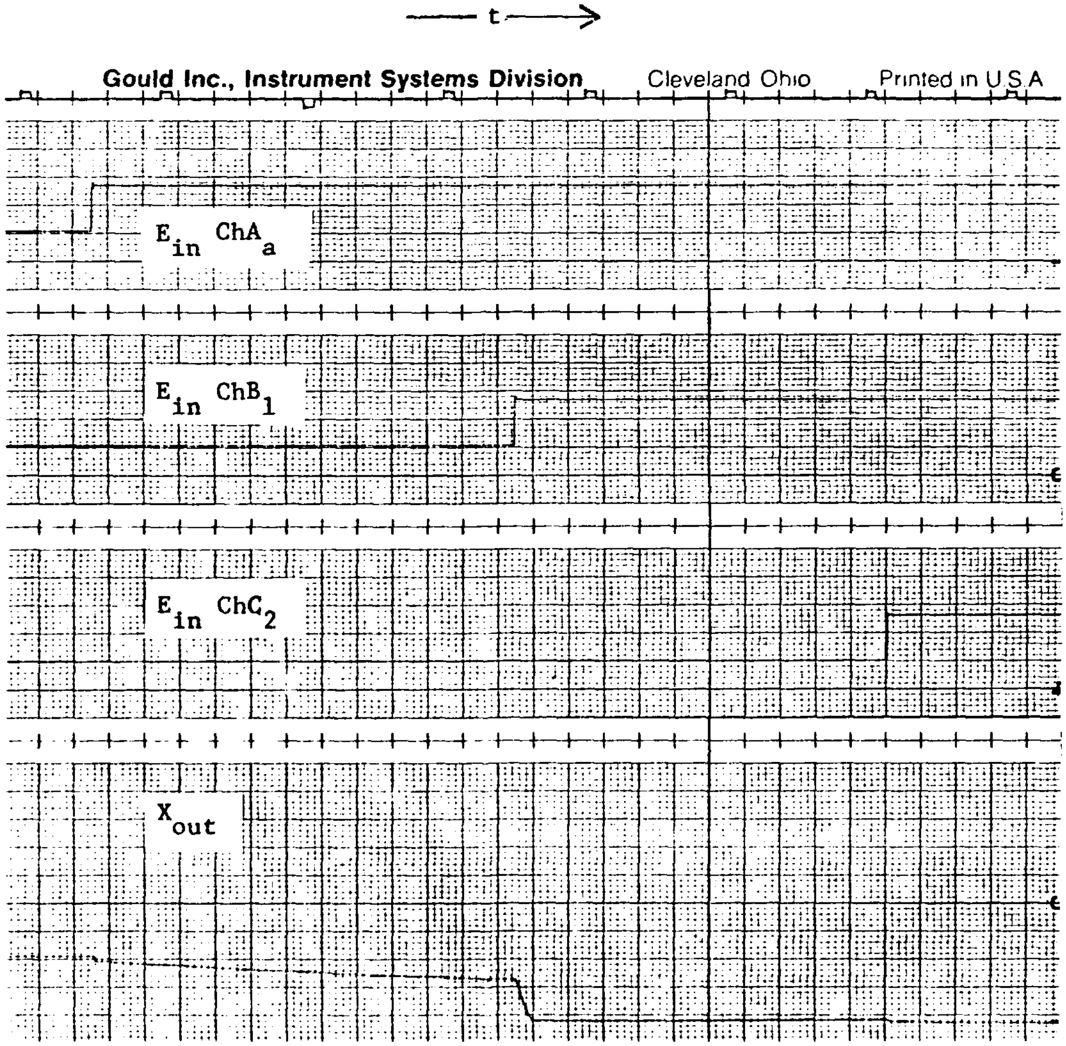
Date Prepared 5/4/79

TEST - Failure Transients - Condition 27




Scale: $E_{in}$ = 1.000 v/div
$X_{out}$ = 0.030 in/div
t = 20 div/sec

FIGURE 198 Failure Transients - Condition 27

the initial deflection is due to the pressure feedback reducing the force output of the two on-line channels. The amount of change of the system output is limited to approximately 10% of the actuator maximum stroke because of the pressure feedback saturation limits. Once the pressure feedback saturates, the on-line channels regain their force output capability and oppose further motion of the system output due to the hardover input into channel A.

The second hardover input into channel B (operating in the on-line mode) causes the actuator output to move to a position 30% of the maximum actuator stroke from the initial biased input position. This final position corresponds to the full actuator motion in the extend direction, since the initial position was a position equal to 50% of the motion in the extend direction. This motion is to be expected, since with the hardover input, two channels are commanded to a full extend position and one channel commanded to the original 50% extend position. The force capability of the two channels with the hardover inputs easily overcomes the force output of the channel without the hardover input, allowing the output to go to a full extend position.

The third hardover input into channel C does not effect the output position of the system. All three channels are commanded to a full extend position, which is the same output position of the system that resulted from the second hardover input (into channel B).

Figure 199 shows the effect of negative hardover input signals applied simultaneously to both the command and model path inputs of channels A, B and C. As with Figure 198, the hardover inputs are applied sequentially to channels A, B and C. For this test condition, channel A is assigned the role of active channel and channels B and C are on-line channels. The effect of the first simultaneous input failure applied to channel A is to create a small (2.5% of the maximum actuator stroke) initial output deviation in the retract direction of the actuator. After the initial movement, the output moves over a 3.5 second time period to a position 10% of the maximum actuator stroke away from the initial position in the retract direction of motion. The initial movement is limited by the dynamic force fight of the on-line and active channel. The movement over the 3.5 second time period is due to the pressure feedback of the on-line channels gradually eliminating the force output of those channels, allowing the active channel to drive the system output in the retract direction. The motion of the output with the active channel subjected to the hardover negative input is limited to approximately 10% of the total actuator stroke. The limit on the output motion is established by the pressure feedback saturation limits. Upon reaching the saturation limit of the pressure feedback, the on-line channels achieve a force output which then opposes the output force of the active channel, stopping the output motion of the system.

As shown on Figure 199, the effect of the second hardover input applied simultaneously to channel B is to cause the output of the system to drive hardover in the retract direction. The time required to reach the final position after the application of the hardover input is .15 seconds. During this motion, the pressure feedback for the on-line channels is not effective and the two channels (A and B) simply overcome the force output of channel C. The third simultaneous input failure does not effect the position of the system output with the third hardover, all three

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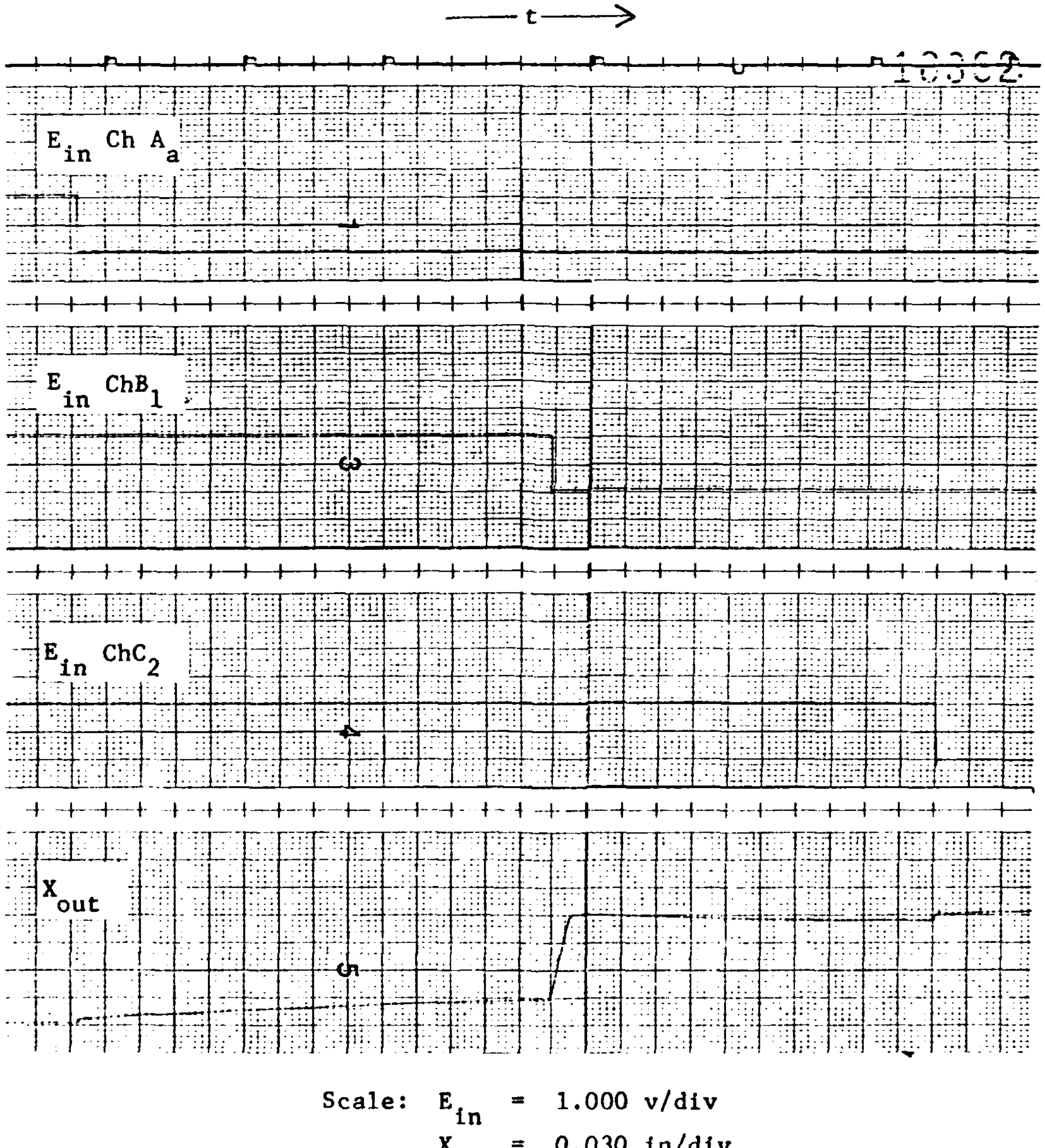
Test Data

TEST ITEM - Grumman - National Water Lift Unit

Date Prepared 5/4/79

TEST - Failure Transients - Condition 28




Scale: $E_{in}$ = 1.000 v/div

$X_{out}$ = 0.030 in/div

t = 20 div/sec

FIGURE 199 Failure Transients - Condition 28

channels are commanded to the same position. Note that the position of the system is at a 50% retract position after the 2nd hardover input. This is consistent with the input being the sum of a 50% extend bias input and a 100% retract input for the hardover command.

Figure 200 shows the effect of positive hardover inputs applied simultaneously to the command and model paths of the control channels while the system is operating with a 10 Hz input with an amplitude of 10% of the input for maximum actuator position. The hardover is applied sequentially to channels A, B and C. The effect of the first hardover into channel A (the active channel) is a steady state shift of the actuator output of 10% of the maximum actuator stroke. The shift is in the extend direction. In addition to the null shift, the actuator response to the sinusoidal 10 Hz input is reduced in amplitude from 10% to 7.5% of the maximum actuator stroke. The effect of the second hardover input into channel B is to cause a null shift of an amplitude equivalent to 35% of the maximum actuator stroke. The amplitude response to the 10 Hz input is reduced to 5% of the maximum actuator stroke. The null shift resulting from the hardover inputs is consistent with a force sharing system operation. For the first hardover input, the null shift is limited by the saturation of the pressure feedback signal. For the second hardover input, the two channels with the hardover input overpower the third channel and drive the system output hardover. The third failure of the channel C input has little effect on the system output since the input change brings the third channel input into agreement with that of channels A and B.

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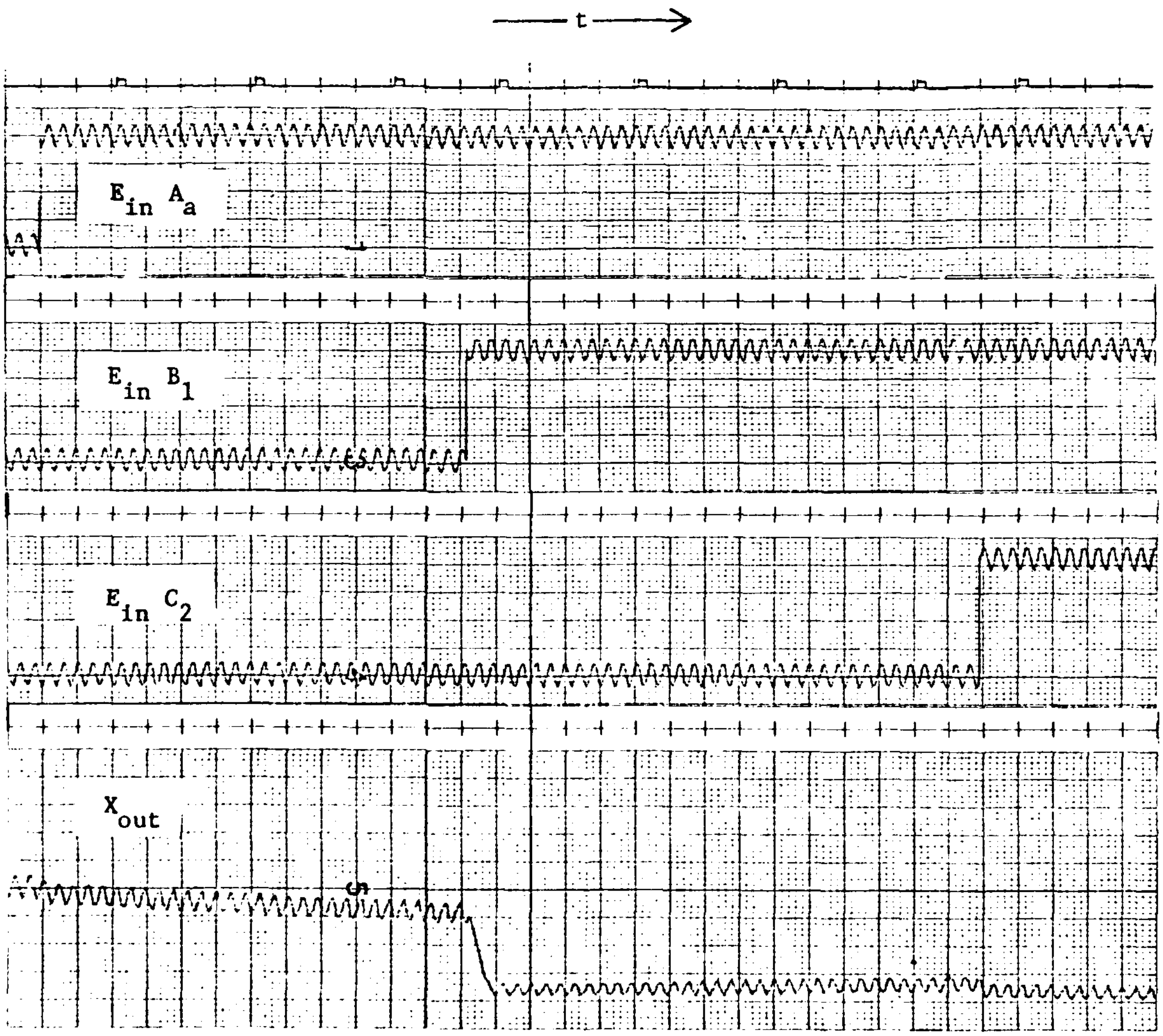
TEST ITEM - Grumman - National Water Lift Unit

Date Prepared 5/7/79

TEST - Failure Transients - Condition 29




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.030 in/div
t = 20 div/sec

FIGURE 200 Failure Transients - Condition 29

Figure 201 shows the effect of a negative hardover input simultaneously applied to the command and model paths of each control channel while the system is operating with a 10 Hz input at an amplitude of 10% of the input for maximum actuator stroke. The hardover input is applied sequentially to channels A, B and C. The effect of the first hardover input into channel A is to cause the steady state operating position to move in the retract direction an amount equal to 10% of the total actuator stroke within a time period of approximately 3.5 seconds. No change in the amplitude of the response to the 10 Hz input occurred with this first input failure. The effect of the second failure into channel B is to cause the actuator output to move in the retract direction an amount equal to 35% of the total actuator stroke. This movement occurs within a .15 second time period. The end position is approximately equal to the full retract stroke position.

The results of the application of the simultaneous hardover failures for both positive and negative inputs are similar. The motion of the system output which results from these failures is consistent with the performance expected from a force sharing system having a low response negative pressure feedback loop of limited range used in two of the three control channels. Without the failure logic detecting failures, the active/on-line system becomes this type of force sharing system.

### 5.5.4 Failure Logic Detection Characteristics

#### 5.5.4.1 General

This section presents the limited test data on the failure detection characteristics of the active/on-line system as evaluated. The data presented is the failure detection characteristics for input failures in terms of amplitude and frequency. The evaluation of the inner loop failure monitoring was not included as part of this investigation. Since the amplitude of the transients resulting from a control channel failure are affected by the characteristics for

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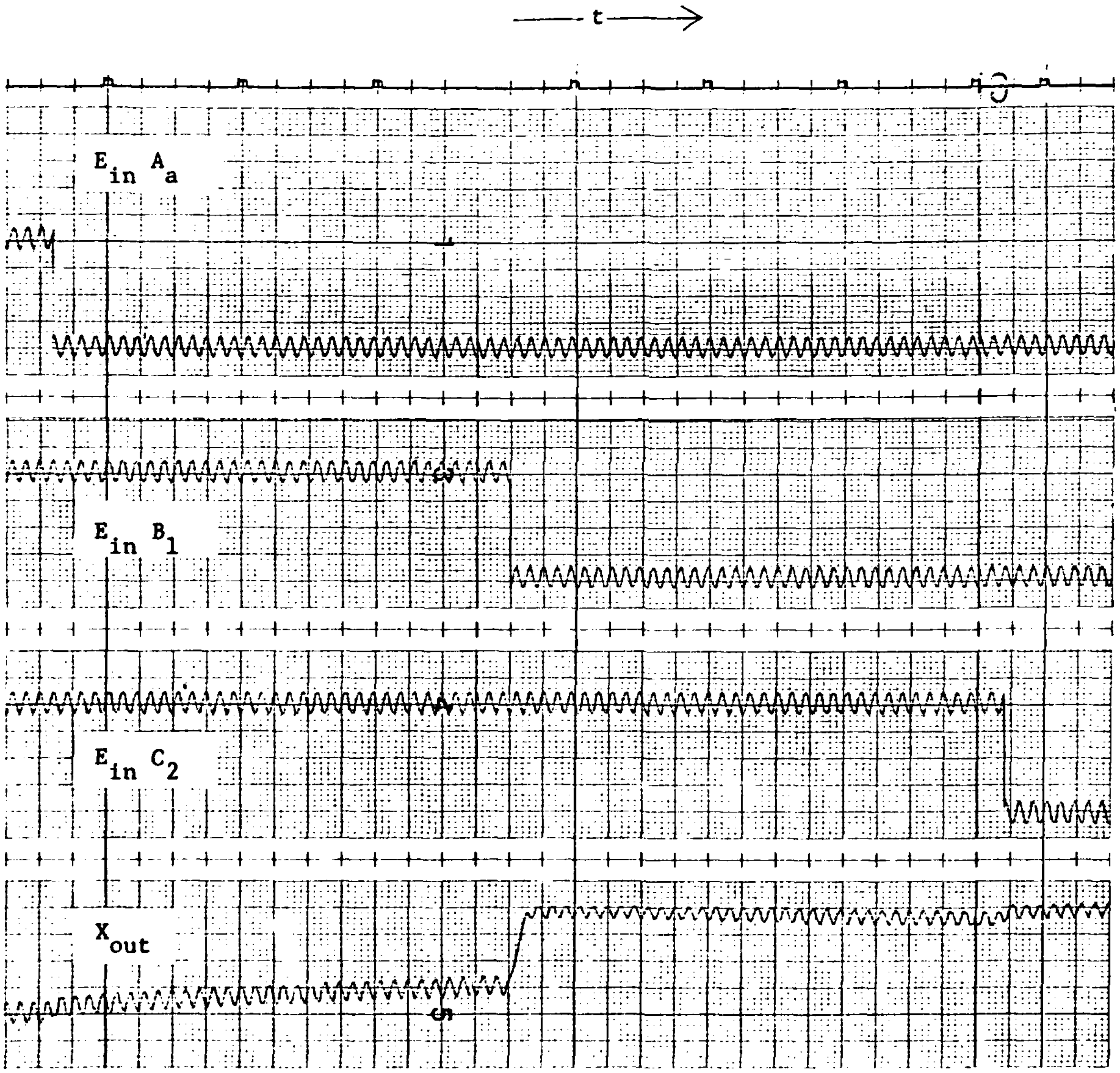
Date Prepared 5/8/79

TEST - Failure Transients - Condition 30




Scale: $E_{in}$ = 0.500 v/div
$X_{out}$ = 0.030 in/div
t = 20 div/sec

FIGURE 201 Failure Transients - Condition 30

the characteristics of the failure detection system, documentation of the characteristics as part of the active/on-line evaluation is worthwhile. The test results present both the static detection level of each channel as measured by an input voltage to the command path input of that channel. The test results present also the highest frequency at which an input amplitude of 110% of the static detection level for a channel will be detected as a failure.

5.5.4.2 Specific

Figure 202 shows data taken in order to establish the failure detection level for channel A slowover failure detection level. A ramp input is applied to the channel A command path input while all other inputs are grounded. The input voltage activating the failure indicate light is defined as the failure detection level.

Table 35 lists the extend and retract direction failure detection input voltages for each channel. The detection level as a function of the configuration used (in terms of the channel assigned the active and on-line modes) is included in the table. As shown on Table 35, the nominal voltage for initiating failure is 1 volt. This corresponds to an input variation of 10% of the input for maximum actuator stroke. The failure detection voltage was not effected by the mode configuration of the channels. The variation in the failure detection voltage was within 10% of the nominal voltage for all test conditions.

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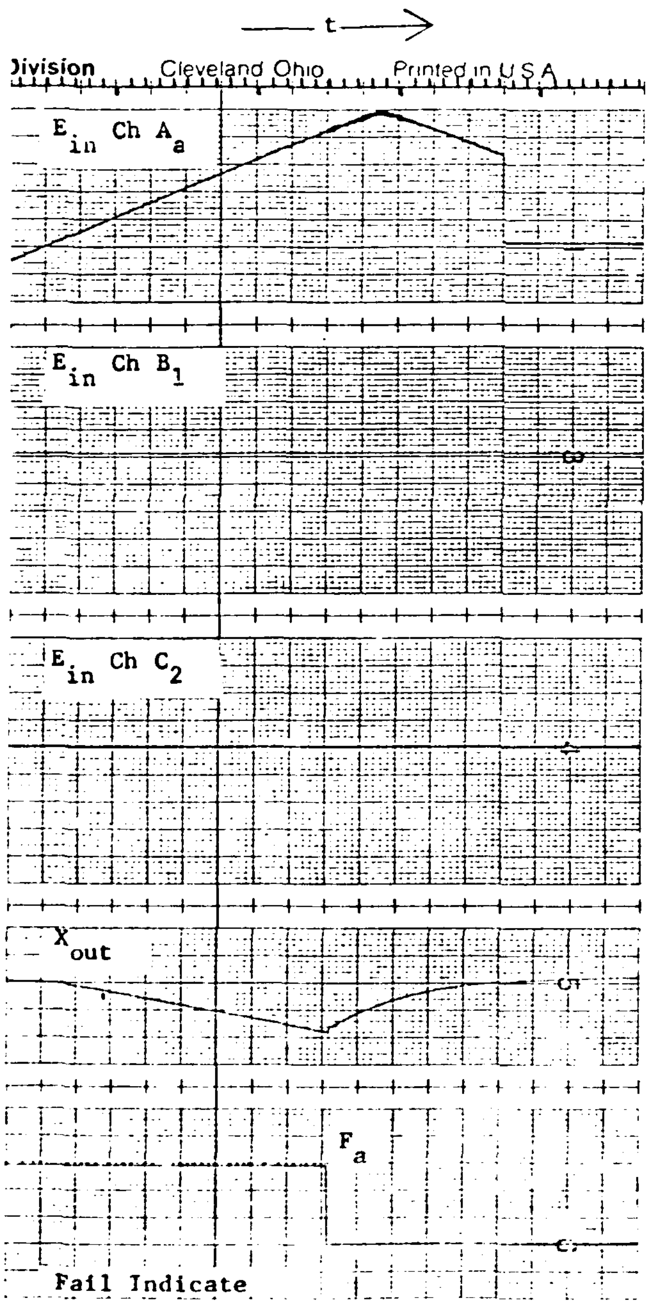
Test Data

TEST ITEM - Grumman - National Water Lift Unit

Date Prepared 6/28/79

TEST - Failure Detection Level - Static - Ch $A_a$ (Extend)




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.003 in/div
t = 2 div/sec

FIGURE 202 Failure Detection Level - Static - Ch $A_a$ (Extend)

TABLE 35

Failure Detection Level - Static

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 6/29/79

TEST ITEM - Grumman - National Water Lift Unit

TEST - Failure Detection Level - Static

| Test Condition | Channel Configuration | Ch | Fail Voltage | |
|---|---|---|---|---|
| | | | Extend | Retract |
| 1 | $A_a\ B_1\ C_2$ | A | +1.03V | -1.03V |
| 1 | $A_a\ B_1\ C_2$ | B | +1.00V | -0.90V |
| 1 | $A_a\ B_1\ C_2$ | C | +1.00V | -1.00V |
| 1 | $B_a\ A_1\ C_2$ | A | +1.00V | -1.03V |
| 1 | $B_a\ A_1\ C_2$ | B | +1.05V | -0.95V |
| 1 | $B_a\ A_1\ C_2$ | C | +1.05V | -1.00V |
| 1 | $C_a\ B_1\ A_2$ | A | +1.05V | -1.00V |
| 1 | $C_a\ B_1\ A_2$ | B | +1.03V | -0.95V |
| 1 | $C_a\ B_1\ A_2$ | C | +1.05V | -1.00V |

Figure 203 shows the data obtained in measuring the channel A dynamic detection level characteristics. The system was configured with channel A the active channel, channel B and C the on-line channels. The input to the command path input of channel A is maintained at an amplitude of 110% of the input required to cause failure detection with a slowover input and the frequency of the input signal varied. As shown on Figure 203, the frequency of the input is gradually being reduced until the fail indicate signal shows that the channel is voted as failed and depressurized.

Table 36 shows the results of the dynamic detection level evaluation. The nominal failure frequency for the test input amplitude is 3 Hz. The lowest frequency at which failure was declared was 2.67 Hz while the highest frequency was 3.7 Hz. The failure detection response was considerably lower than that of the system, indicating that oscillatory failures would not be detected over a large portion of the actuator system frequency response. As shown on Table 36, the failure detection frequency was a function of the particular channel being tested and not the configuration of the system with respect to the operational mode of the system.

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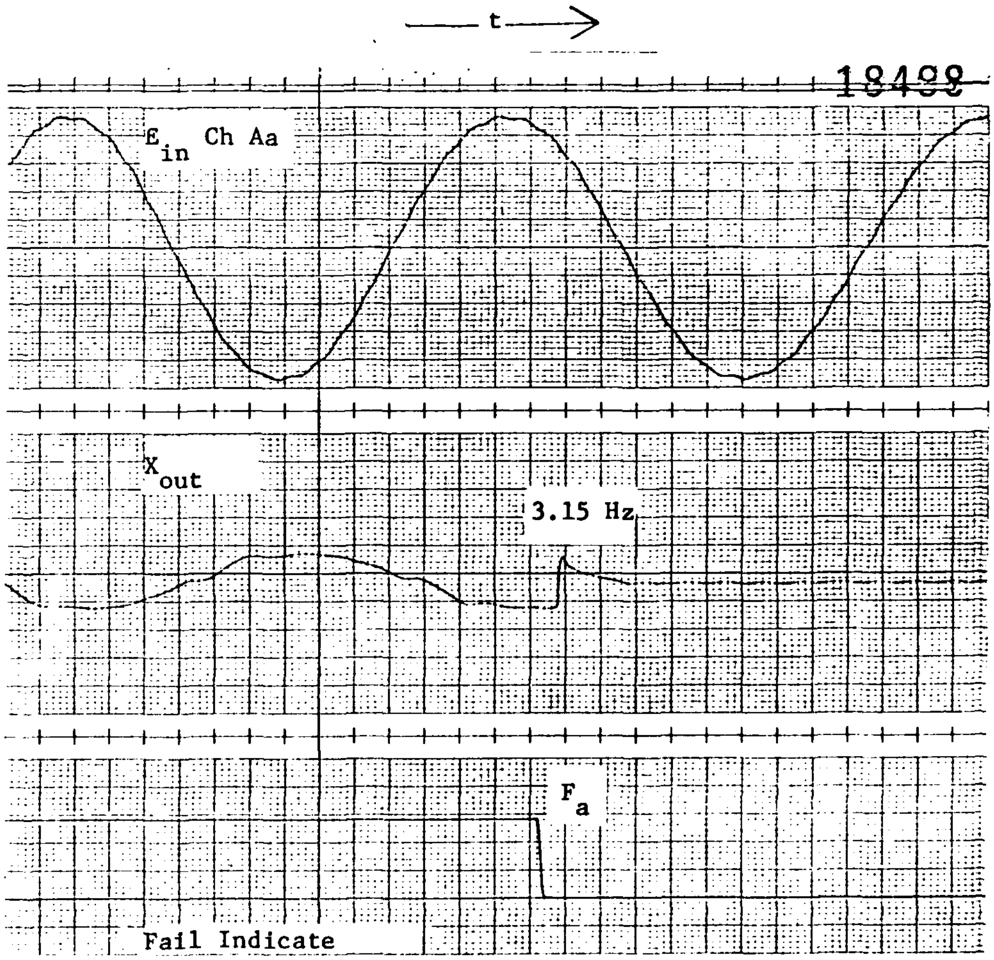
TEST ITEM - Grumman - National Water Lift Unit

Date Prepared 6/28/79

TEST - Failure Detection Level - Dynamic - Ch Aa




Scale: $E_{in}$ = 0.050 v/div
$X_{out}$ = 0.0033 in/div
t = 200 div/sec

FIGURE 203 Failure Detection Level - Dynamic - Ch Aa

TABLE 36

Failure Detection Level - Dynamic

DYNAMIC CONTROLS, INC.
Test Data

Date Prepared 6/29/79

TEST ITEM - Grumman - National Water Lift Unit

TEST - Failure Detection Level - Dynamic

| Test Condition | Channel Configuration | Ch | Fail Hz |
|---|---|---|---|
| 1 | $A_a$ $B_1$ $C_2$ | A | 3.03 |
| 1 | $A_a$ $B_1$ $C_2$ | B | 3.70 |
| 1 | $A_a$ $B_1$ $C_2$ | C | 2.67 |
| 1 | $B_a$ $A_1$ $C_2$ | A | 3.17 |
| 1 | $B_a$ $A_1$ $C_2$ | B | 3.70 |
| 1 | $B_a$ $A_1$ $C_2$ | C | 2.63 |
| 1 | $C_a$ $B_1$ $A_2$ | A | 3.03 |
| 1 | $C_a$ $B_1$ $A_2$ | B | 3.70 |
| 1 | $C_a$ $B_1$ $A_2$ | C | 2.78 |

## 6. CONCLUSIONS AND RECOMMENDATIONS

The force sharing and active/on-line Fly-By-Wire mechanizations performed satisfactorily in terms of providing a Fly-By-Wire secondary actuator with "two failure" tolerance capability. Both demonstrators used electronics which would require development in order to be representative of the electronics which are a necessary part of the mechanization when it is used for flight hardware. The actuator portion of the demonstrators were representative of the hardware which could be used in an actual aircraft installation.

The nominal measured performance of both mechanizations appeared satisfactory for secondary actuator applications. The frequency response and distortion characteristics of both mechanizations were similar. The active/on-line mechanization exhibits better threshold and hysteresis characteristics than the force sharing system, probably due to the use of higher pressure gain control valves.

The addition of the pressure equalizer to the basic force sharing system did increase that mechanization's tolerance to control input mismatches. The pressure equalizer did not affect the nominal performance of the system in the other characteristics measured. The use of the pressure equalizer with the integrator did not benefit the measured performance of the system. The force sharing system did exhibit a higher dynamic threshold with the integrator than without.

The system output motion transients with injected failures remained below 2% of the total actuator stroke for both systems and the majority of the test conditions. The failure transient for the force sharing system was generally on the order of 1% of the maximum actuator stroke and was lower than that measured on the active/on-line system. However, the difference between the failure induced transients measured with the two systems may be because the detection level for channel mismatches were different. The detection level was 4% of the maximum command input for the force sharing system and 10% of the maximum command input for the active/on-line system. The failure detection level differences affect primarily the transient associated with slowover type failures.

The transient duration characteristics were better for the active/on-line system than for the force sharing mechanization. The active/on-line system limited the duration of the failure transients after failure detection to .15 seconds or less. The failure transient duration for the force sharing system was nominally .85 seconds.

Simultaneous failures were not correctly detected by either mechanization. The time window limitation defining "simultaneous failures" depends on the failure logic time delay and latching characteristics.

The active/on-line system requires 6 separate inputs for the command input. The force sharing system requires 4 separate inputs to accomplish the same failure mode capability. The additional input transducers required by the active/on-line system is a disadvantage in terms of cost and maintenance reliability.

The response characteristics of the failure logic for both systems was considerably below the response of the actuator itself. This would allow oscillatory failure inputs to drive the system output without the failure being detected. Since both systems operate as a force summation system at high frequencies, the response of the system to oscillatory channel failures that are not detected by the failure logic is amplitude limited. However, the effect of the output motion at the frequencies where the failure logic does not detect input failures should be considered when using either system for a flight application.

Based on the testing performed and the test results obtained, it is concluded that both the force sharing and the active/on-line configurations are mechanizations which perform the desired functions of an electro-hydraulic secondary actuator redundant system. It is recommended that any further evaluation should address the other relevant aspects of the mechanizations such as weight, volume, power consumption, cost and life cycle costs for flight control system application.



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